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OBJECTIVE ASSESSMENT AND PROMOTION OF PHYSICAL ACTIVITY IN OLDER ADULTS LIVING IN RESIDENTIAL CARE FACILITIES

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Dissertation presented in partial fulfillment
of the requirements for the degree of
Doctor in Biomedical Sciences

LEUVEN 2015

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Leuven, 2 juli 2015

This study was conducted under the authority of the Policy Research Centre on Sports, supported by the Flemish Government.
Dit proefschrift werd mede mogelijk gemaakt dankzij de steun van het Steunpunt Sport van de Vlaamse Overheid.

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ACKNOWLEDGEMENTS - DANKWOORD

De trein, altijd een beetje reizen...

Zondag 18 september 2005. De eerste treinrit naar de studentenstad Leuven. Ik zou Lichamelijke Opvoeding en Bewegingswetenschappen aan FaBeR gaan studeren. Na het behalen van mijn masterdiploma kreeg ik de kans om een doctoraat te starten, een treinreis die een kleine 5 jaar zou duren. Met de nodige vertragingen en stakingen heb ik vandaag, met enige trots, mijn eindhalte bereikt. Het was een leerrijke periode met fijne herinneringen, waarbij ik ook mijn persoonlijke vaardigheden (verder) kon ontwikkelen. Als ik terugblik op de voorbije 5 jaar, heb ik verschillende haltes en stations doorkruist: de zoektocht naar de 'gap in literature', het rekruteren van deelnemers, het testen van en het (geduldig) luisteren naar de oudere deelnemers, het uren/dagen-lang analyseren van data, het schrijven en herwerken (en herwerken...) van publicaties, het belang van bewegen proberen toe te lichten aan ouderen en vrienden/familie trachten uit te leggen wat ik daar in het verre Leuven allemaal aan het doen was. Het werd een reis met een aantal hindernissen, maar om mijn trein op de rails te houden kon ik gelukkig op een aantal belangrijke personen rekenen.

We vertrekken uit Leuven – Tijdens mijn eerste halte wil ik vooreest mijn promotor Prof. dr. C. Delecluse, huidige decaan van onze faculteit, bedanken. Christophe, 5 jaar geleden kreeg ik de kans om bij jou een doctoraat te starten. Een unieke kans die ik zeker niet wou laten liggen! In het begin had ik goed onderbouwde argumenten nodig om je te overtuigen van mijn onderzoeksideeën bij de oudste doelgroep. Het was ook niet altijd even gemakkelijk omwille van je drukke agenda, maar door jouw constructieve feedback, de nodige vrijheid die ik kreeg en het vertrouwen, sta ik hier vandaag. Telkens weer was ik (en ben ik nog steeds) onder de indruk van jouw uitgebreide kennis, overtuigings- en presentatiekracht en enthousiasmerende omgang met zowel studenten als collega's. Ook mijn co-promotoren Prof. dr. F. Boen en Prof. dr. J. Seghers wil ik van harte bedanken. Filip, jouw enthousiasme tijdens elke vergadering gaf me de moed door te zetten. De bemoedigende mails, maar de tevens kritische en opbouwende feedback die je steeds tijdig aanleverde deden de trein een versnelling hoger schakelen. Jan, bedankt voor jouw kritische zin en de fijne gesprekkken. Ik kon steeds bij jou terecht met vragen, je deur stond altijd open. Bedankt voor de fijne samenwerking tijdens het schrijven van mijn masterproef en mijn eerste werkervaring aan KU Leuven. Christophe, Filip en Jan, hartelijk dank! Ik kon me geen betere promotoren wensen.

Voorliggend manuscript kon niet tot stand komen zonder de kritische zin van de leden van mijn doctoraatscommissie en de juryleden van mijn examencommissie. Hierbij wil ik dan ook Prof. dr. Johan Lefevre, voorzitter van het Departement Bewegingswetenschappen, Prof. dr. Rik Gosselink, Prof. dr. Koen Milisen, Prof. dr. Bart Vanreusel en Prof. em. dr. Marijke Hopman-Rock bedanken voor hun bereidheid om dit manuscript te beoordelen. Door hun kritische kijk en de interessante

suggesties kon dit manuscript naar een hoger niveau getild worden. Een oprecht woord van dank aan Prof. em. dr. Marijke Hopman-Rock om te willen afreizen naar België om deel uit te maken van mijn jury.
Hier wil ik ook alle co-auteurs bedanken voor hun bijdrage aan 1 of meerdere papers. Enkele collega's van Gasthuisberg wil ik bedanken voor hun hulp tijdens de validatiestudie: Prof. dr. Thierry Troosters, dr. Daniel Langer en dr. Hans Vanremoortel, bedankt! Tevens wil ik de klankbordgroep van WP5 bedanken voor hun welgekomen suggesties en uiteraard ook het Steunpunt Sport voor de financiële ondersteuning.

Stiekem verlang ik om terug te reizen naar West-Vlaanderen, maar ik moet toegeven dat ik één iets zeker zal missen (naast de prachtige omgeving waarin ik 5 jaar mocht werken): de collega's. Ik wil dan ook als eerst mijn collega's van het Steunpunt 'onder de Alma' bedanken. Evelien VR, Ruben, Sara, Maarten, Stijn, Irena, Evelien M, Sofie DB, Iona, Eva en Hannes, ik vond het een eer om met elk van jullie de bureau te delen. Hoewel ik tijdens de laatste schrijffase vaak thuis werkte, vond ik het altijd fijn om weer even op bureau te zijn. We hebben heel wat gelachen en ook de talloze lunchpauzes in de Alma of bij de Chinees zal ik niet gauw vergeten. Bedankt! Evelien, ik wil jou in het bijzonder bedanken. Zonder jou stond ik hier vandaag zeker niet. Naast een fantastische collega heb ik er een fantastische vriendin bij. Ik wil jou en Vincent ook bedanken voor het aanbieden van 'Bed&Breakfast' toen ik geen vaste verblijfplaats meer had in Leuven.

Collega's van gebouw De Nayer en het Gymnasium wil ik tevens danken voor de aangename werksfeer op onze faculteit. In het bijzonder Evi, Joke, Ann-Sophie, Julie, Gommaar, Stijn D, Tineke, Karen, Siacia, de collega's van PortaAL, Rosalie, Johan P, Hanne en Katrien; jullie steun was onmisbaar tijdens mijn treinreis. Dank ook voor de fijne lunchpauzes en babbels. Een speciaal woord van dank aan Evi&Gommaar, Ann-Sophie, Julie en Joke. Niet enkel als collega's, maar ook als vrienden hebben we mooie momenten beleefd in Leuven en daarbuiten (Milaan, de Ardennen, sportieve uitdagingen, etentjes...). Ik hoop uit de grond van m'n hart dat de eindhalte van mijn doctoraat niet de eindhalte van onze vriendschap betekent.

Verder richt ik ook graag een woord van dank tot de decaan van de faculteit Prof. dr. Christophe Delecluse, de voorzitter van het Departement Bewegingswetenschappen Prof. dr. Johan Lefevre en het afdelingshoofd van de onderzoeksgroep Fysieke Activiteit, Sport & Gezondheid Prof. dr. Filip Boen, voor de goede omkadering en ondersteuning die jullie bieden aan alle doctoraatsstudenten.
Een dankjewel aan alle mensen van de technische en administratieve diensten van onze faculteit. In het bijzonder Sonja, Annita, Virginie en Nele; bedankt voor jullie paraatheid, administratieve hulp en glimlach, elke dag opnieuw.

Gelieve over te stappen in Brussel of Gent – Af en toe maakte ik een tussenstop tijdens mijn traject Leuven – Diksmuide. Brussel was vaak de halte voor vergaderingen en in Gent plande ik soms een ontspannende avond of lunch met oud-collega's en vrienden. In het bijzonder; Sofie DS, Sofie DB, Celine&Matthias, Hanne, Nele&Sam, Stefanie&Lode, jullie maakten mijn reis des te leuker. Een speciaal dankwoordje voor Ingrid en Katrien voor de fantastische summer school in Verona.

De volgende haltes zijn… Tijdens mijn dataverzameling heb ik een groot stuk van West-Vlaanderen doorkruist. Bedankt aan alle deelnemers. Zonder de directies van de woon- en zorgcentra en serviceflats, de Thuiszorgwinkel en uiteraard de bewoners, had ik hier vandaag niet gestaan. Een welgemeende dank om mijn onderzoek een kans te geven alsook voor het invullen van die ellenlange vragenlijsten en het voltooien van de lastige fysieke tests. Alle onderzoeksstage- en masterproefstudenten, bedankt voor jullie inzet en hulp tijdens de dataverzameling.

We komen aan in Diksmuide – Ook naast het werk zijn er heel wat mensen die me gesteund hebben. Mijn vrienden uit Diksmuide en omstreken wil ik bedanken voor de leuke etentjes, citytrips, toertochten en ontspannende weekends. Lien&Steven, Tina&Anthony, Nele&Karel, Matilde&Stefaan, Silvie&Dieter, Evelien M, Ine&Maarten en alle anderen, bedankt dat ik steeds bij jullie terechtkon voor de nodige ontspanning en gezelligheid. Mijn familie en schoonfamilie wil ik danken voor hun steun, vriendschap en liefde. De Feestdagen en verjaardagsfeestjes waren steeds momenten om naar uit te kijken. Pepe&Francine, Marijke&Marc, tantes, nonkels, neefjes, nichtjes, schoonzussen en schoonbroers; bedankt!
In Diksmuide wil ik in het bijzonder ook mijn ouders bedanken. Een oprecht woord van dank voor de vele kansen die ik kreeg en nog steeds krijg. Ik vertoefde vaak in Leuven, maar was altijd blij als ik terug 'thuis' mocht komen. Bedankt voor de steun, het warme nest, het lekkere eten, de leuke babbels en zoveel meer... Bedankt mama en papa!

We komen aan in Koksijde, eindbestemming van deze trein – Tot slot wil ik de belangrijkste persoon in mijn leven bedanken. Dries, bedankt voor alles wat je spontaan voor me deed en nog steeds doet. Jij hield mijn trein rijdende. Ik ben trots dat ik sinds 4 oktober 2014 je vrouw mag zijn en ik ben heel blij dat ik samen met jou naar mijn volgende halte Koksijde mag reizen. Ik zie je graag – oneindig en terug.

Aan iedereen een welgemeende dankjewel! Ik kijk vol enthousiasme uit naar mijn volgende treinreis!
Sofie

Donderdag 2 juli 2015, Diksmuide

ENGLISH SUMMARY

The world's population is aging rapidly, as both life expectancy and the proportion of older people are increasing. This aging of the population is an indicator of improved health conditions and should be considered as a success story. However, it is also one of the main challenges that the world is facing because there is a growing need to prevent age-associated declines and diseases such as cardiovascular disease, diabetes, dementia, and osteoporosis. Physical activity (PA) has been identified as a major public health priority because it can help to prevent, or even reverse age-associated declines and losses of many physical and psychological variables.

The present doctoral thesis, entitled 'Objective assessment and promotion of PA in older adults living in residential care facilities' focuses on three interrelated aims: assessment (**CHAPTER 1**), screening (**CHAPTER 2**), and intervention (**CHAPTER 3**). The first aim was to investigate the validity of two motion sensors in institutionalized older adults (***Paper 1*** and ***Paper 2***). Accurate quantification of both PA and sedentary behavior is important for screening, goal setting, and program evaluation. The second aim was to examine the link between muscle strength and functional performance, and to identify functionally relevant cut-off values for knee extension strength in older adults (***Paper 3***). It is important to determine physical characteristics related to functional deterioration, as this will eventually lead to a loss of independence and institutionalization, and an increase in healthcare costs. Finally, the last aim was to examine the short- and long-term effects on PA, functional performance and muscle strength of a 10-week cycle ergometer intervention in assisted living facilities (***Paper 4***). PA promotion in older adults is important because a large proportion of the older population is not regularly involved in PA.

Paper 1 examined the accuracy of a hip-worn and ankle-worn piezoelectric pedometer and the multisensor Sensewear Mini (SWMini) in measuring steps during daily life activities in nursing home residents (N=68; mean age=86 years). The results revealed that the multisensor and hip- and ankle-worn pedometer significantly underestimated step counts, although measurement accuracy was higher when the pedometer was worn at the ankle. Moreover, pedometer accuracy improved as walking speed increased. The ankle-worn piezoelectric pedometer proved to be acceptably accurate for quantifying steps at walking speeds of ≥2.35 km/h. Next to step counts, energy expenditure (EE) is a common outcome when assessing PA in daily life. Therefore, the purpose of ***Paper 2*** was to examine the validity of the SWMini to measure EE during rest and during the performance of daily life activities in a sample of nursing home residents (N=60; mean age=86 years). The results showed that the SWMini can be applied for describing and quantifying sitting time in institutionalized older adults because significant increases between sitting periods and daily life activity tasks were found. In addition,

analyses revealed that the SWMini demonstrated good agreement with indirect calorimetry, although the device underestimated EE. Age was determined as a key factor of accuracy, suggesting that accurate age- and activity-specific algorithms should be developed.

The second chapter of this doctoral thesis examined whether knee extension and handgrip strength, measured using two field tests, are good predictors of functional performance among older adults (≥60 years). In total, 770 community-dwelling older adults, 104 older adults living in assisted living facilities and 73 nursing home residents were included in ***Paper 3*** to cover a broad range of strength performance and functionality levels. Results revealed that both handgrip and knee extension are important predictors of functional performance in older adults. In assisted living facilities only, knee extension strength proved to be a better predictor of functional performance than handgrip strength. Early identification of persons with muscle weakness might create opportunities for developing and implementing strategies to counteract disability. Specific cut-off values for functionally relevant muscle strength for men and women respectively were set at 0.40 and 0.31 kg per kg body weight (BW) for lower body strength and at 0.43 and 0.31 kg per kg BW for upper body strength. These cut-off values should be used in clinical practice to detect and double check older adults at risk for muscle weakness, using simple field tests.

The results obtained in ***Paper 3*** contributed to the development of a PA intervention in ***Paper 4***. In this paper, ergometer cycling was used for the promotion of PA among residents living in an assisted living facility (N=95, mean age=82 years). Ergometer cycling trains the cardio-respiratory system as well as lower body muscles. The purpose of this last paper was to evaluate the short- and long-term effectiveness of an ergometer cycling intervention, comparing 2 coaching procedures: (1) structured fitness coaching (STRUC) with permanent assistance, consisting of three weekly sessions on a cycle ergometer, and (2) autonomy-supportive coaching (AUT) based on the Self-Determination Theory, consisting of an individualized cycle ergometer program with minimal coaching contact. Especially the autonomy-component considerably differed between both intervention groups as participants in AUT had to complete the program on their own, without supervision of the coach. The effects on adherence rate, PA, functionality and muscle strength were assessed at baseline, post-intervention (10 weeks after pre) and at follow-up (24 weeks after post). Results showed that minimal contact with a coach is sufficient to promote ergometer cycling in older adults, but training volumes are higher in both the short- and long-term when training is strictly supervised. Contrary to our hypotheses, stimulating autonomy in this age group did not result in higher long-term adherence rates. Self-reported moderate intensity PA increased from pre to post in both intervention groups in comparison with the control group. However, only AUT showed short-term gains in daily EE. At last, older adults who exercised more frequently on the cycle ergometer showed better short-term results on functionality and muscle strength, even though improvements were small.

The present doctoral thesis offers important information regarding screening of older adults at risk for functional impairment, and regarding objective assessment and promotion of PA in older adults living in residential care facilities. Researchers and practitioners can use this information for future PA recommendations and PA interventions in the old and old-old.

DUTCH SUMMARY - SAMENVATTING

Omwille van de stijgende levensverwachting vergrijst de bevolking wereldwijd in een snel tempo. De veroudering van de bevolking is een succesverhaal, maar het vormt tevens een belangrijke uitdaging voor onze maatschappij. De vergrijzing brengt immers een aantal leeftijdsgerelateerde ziektes met zich mee (bv. hart- en vaatziekten, diabetes, dementie en osteoporose) en leidt tot een toename van het aantal ouderen dat fysiek niet langer in staat is om dagdagelijkse taken zelfstandig uit te voeren. Onderzoek heeft aangetoond dat fysieke activiteit (FA) een positieve invloed heeft op de fysieke en mentale gezondheid en helpt om ouderen langer zelfstandig te laten leven.

Voorliggend doctoraatsproject, getiteld ‘Objectieve meting en promotie van FA bij ouderen die in een residentiële zorgsetting wonen’ bestaat uit 3 samenhangende doelen: meting (**HOOFDSTUK 1**), screening (**HOOFDSTUK 2**) en interventie (**HOOFDSTUK 3**). In **HOOFDSTUK 1** worden beweegmonitoren gevalideerd bij geïnstitutionaliseerde ouderen (***Artikel 1*** en ***Artikel 2***). Het objectief meten en analyseren van FA en sedentair gedrag is belangrijk voor screening, het stellen van beweegdoelstellingen en evaluatie van beweegprogramma’s. **HOOFDSTUK 2** focust zich op het verwerven van inzicht in de relatie tussen spierkracht en functionaliteit bij ouderen (***Artikel 3***). In dit tweede hoofdstuk worden tevens functioneel relevante drempels voor spierkracht bepaald. Het is belangrijk om fysieke karakteristieken gerelateerd aan functionele beperking te identificeren, daar een daling in functionaliteit uiteindelijk zal leiden tot toenemende afhankelijkheid en opname in een zorginstelling. Het laatste doel van dit doctoraatsproject (**HOOFDSTUK 3**) is het evalueren van de korte en lange termijn effecten op FA, functionaliteit en kracht van een hometrainerinterventie in serviceflats (***Artikel 4***). De promotie van FA bij ouderen is belangrijk aangezien heel wat ouderen onvoldoende fysiek actief zijn.

Artikel 1 evalueerde de validiteit van een piëzo-elektrische pedometer gedragen aan de heup en aan de enkel, alsook van de activiteitsmonitor Sensewear Mini (SWMini) voor het meten van het aantal stappen bij bewoners van woon- en zorgcentra (N=68; gemiddelde leeftijd=86 jaar). De resultaten toonden een significante onderschatting van het aantal stappen door zowel de activiteitsmonitor als de stappenteller, hoewel de stappenteller gedragen aan de enkel het meest betrouwbaar was. Daarenboven had wandelsnelheid een positieve invloed op het foutenpercentage. ***Artikel 1*** toonde aan dat een piëzo-elektrische stappenteller aan de enkel accuraat is voor ouderen met een wandelsnelheid ≥2.35 km/u.
Naast het aantal stappen is energieverbruik een vaak gebruikte maat voor dagdagelijkse FA. Het doel van ***Artikel 2*** was het nagaan van de validiteit van de activiteitsmonitor SWMini voor het meten van energieverbruik tijdens rust en tijdens het uitvoeren van dagdagelijkse activiteiten bij bewoners van woon- en zorgcentra (N=60; gemiddelde leeftijd=86 jaar). De resultaten toonden aan dat de SWMini

gebruikt kan worden voor het beschrijven en kwantificeren van zitgedrag bij geïnstitutionaliseerde ouderen daar een significant verschil werd gevonden tussen het energieverbruik in rust en bij het uitvoeren van dagdagelijkse activiteiten. Wat betreft totaal energieverbruik werd een significante correlatie gevonden tussen energieverbruik gemeten door de SWMini en indirecte calorimetrie, alhoewel de SWMini het energieverbruik significant onderschatte. Activiteit- en leeftijdsspecifieke algoritmen dienen ontwikkeld te worden voor de oudste ouderen, daar leeftijd een bepalende factor bleek te zijn voor een accurate meting van energieverbruik door de activiteitsmonitor.

HOOFDSTUK 2 van deze doctoraatsthesis onderzocht of knie-extensiekracht en handknijpkracht goede voorspellers zijn voor functionaliteit bij ouderen (≥60 jaar). In totaal werden 770 thuiswonende ouderen, 104 bewoners van serviceflats en 73 bewoners van woon- en zorgcentra opgenomen in ***Artikel 3***. Hierdoor had de studiepopulatie een groot bereik wat betreft spierkracht en functionaliteit. Resultaten toonden aan dat zowel handknijpkracht als knie-extensiekracht belangrijke voorspellers zijn van functionaliteit bij ouderen. Daarenboven bleek dat knie-extensiekracht een betere voorspeller is van functionaliteit bij bewoners van serviceflats. In ***Artikel 3*** werden tevens functioneel relevante drempelwaarden voor spierkracht berekend. Voor mannen werden de drempelwaarden voor handknijpkracht en knie-extensiekracht specifiek bepaald op 0.40 en 0.43 kg per kg lichaamsgewicht. Voor vrouwen was de waarde 0.31 kg per kg lichaamsgewicht voor zowel handknijpkracht als knie-extensiekracht. Het vroegtijdig identificeren van risicovolle ouderen kan opportuniteiten creëren voor het ontwikkelen van strategieën om functionele beperking tegen te gaan. Daar eenvoudige veldtesten werden aangewend, kunnen bovenstaande drempelwaarden gemakkelijk worden toegepast in de praktijk.

De resultaten van ***Artikel 3*** hebben bijgedragen tot de ontwikkeling van een aangepaste bewegingsinterventie bij ouderen. In ***Artikel 4*** werd het fietsen op een hometrainer gebruikt om de FA bij bewoners van serviceflats te bevorderen (N=95; gemiddelde leeftijd=82 jaar). Fietsen traint zowel het cardiovasculair systeem als de spieren van het onderste lidmaat. Het doel van **HOOFDSTUK 3** was om de korte en lange termijn effecten van een 10-weken durende hometrainerinterventie in serviceflats te onderzoeken. Hiertoe werden 2 coachingsstrategieën met elkaar vergeleken: (1) gestructureerde fitness coaching, bestaande uit 3 begeleide sessies op een hometrainer per week en (2) autonomie-ondersteunende coaching gebaseerd op de Zelf-Determinatietheorie, bestaande uit een geïndividualiseerd hometrainerprogramma en minimaal contact met een coach. De interventiegroepen differentieerden voornamelijk in de autonomie-component, gezien de deelnemers uit de autonomie-ondersteunende groep zelf verantwoordelijk waren voor het volgen van het fietsprogramma en de keuze hadden wanneer en met wie ze wilden fietsen. FA, functionaliteit en kracht werden gemeten voor de training (pre), na de training (post) en 6 maanden na het beëindigen van de interventie (follow-up). De resultaten toonden aan dat minimaal contact met een coach voldoende is om het fietsen op een hometrainer te promoten bij ouderen wonende in een serviceflat, hoewel meer structuur en ondersteuning leiden tot grotere trainingsvolumes op korte en lange termijn. Autonomie-ondersteuning bleek bij deze oudere leeftijdsgroep niet te resulteren in grotere deelname op lange termijn. Zelfgerapporteerde matige FA nam toe van pre naar post in beide interventiegroepen. Aan de andere kant werd enkel in de autonomie-ondersteunende groep een stijging gerapporteerd voor dagelijks energieverbruik. Tot slot toonden de resultaten aan dat frequent fietsen op een hometrainer een positieve, doch kleine invloed heeft op de functionaliteit en de spierkracht bij bewoners van een serviceflat.

Voorliggende doctoraatsthesis beoogt een wetenschappelijke bijdrage te leveren met betrekking tot de screening van ouderen met risico op functionele problemen en de objectieve meting en promotie van FA bij geïnstitutionaliseerde ouderen. Onderzoekers en experts in het veld kunnen de resultaten aanwenden bij het uitwerken van toekomstige aanbevelingen en interventies voor ouderen.

PART 1

GENERAL INTRODUCTION AND OUTLINE

One of the most common fallacies about old age is the perception that aging is only associated with losses and decline. This perception is not consistent with the self-perception of the majority of older adults. Importantly, many of the age-related declines in physical and psychological variables can be prevented or even reversed by regular physical activity (PA) (Jones & Rose, 2005).

This introduction will first focus on the definition and impact of aging. Second, the role of PA in the aging process will be discussed. Additionally, the importance of valid measures of PA in older adults will be described. The research aims of the present manuscript will be considered at the end of the introduction.

1. DOUBLE GRAYING

The world's population is aging rapidly, as both life expectancy and the proportion of older people are increasing.

1.1. Life expectancy

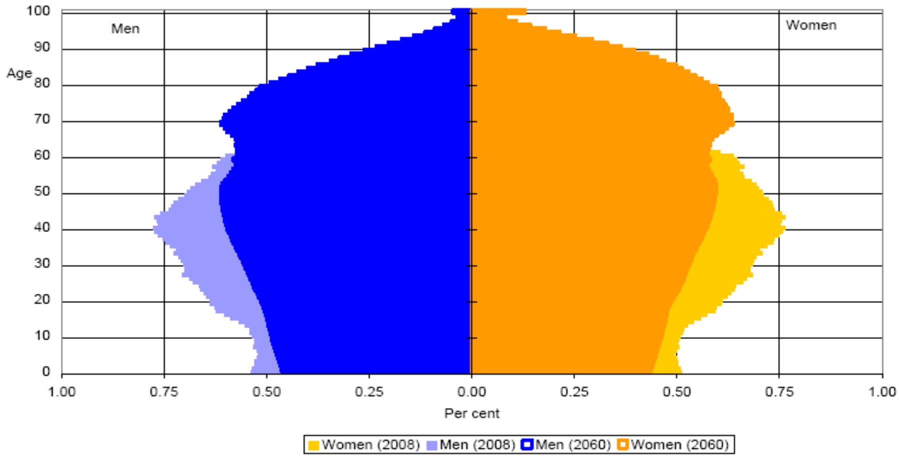
Since 1970 life expectancy in Europe has increased by 6 to 8 years (Leon, 2011) because of higher living standards, lower infant mortality rate, improvements in medicine and surgery, and better education (Bunker, 2001; Eurostat, 2014a). Current life expectancy of European men and women at birth is 77.5 and 83.1 years, respectively. In addition, the number of centenarians (aged 100 years or over) is increasing (Eurostat, 2014b).

1.2. Proportion of older people

Higher life expectancy and lower birth rate will transform the shape of the age pyramid (*Figure 1*). There will be a shift towards a much older population structure and a declining share of younger and working age persons in the total population. In 2013, persons considered to be of working age (15-64 years) accounted for 66.2% of the European population. Older persons (≥aged 65 years) had a share of 18.2%. However, it should be noted that the proportion of the older population is higher in more developed regions (i.e., Europe, Northern America, Australia, Japan and New Zealand) than in the less developed regions (*Figure 2*).
Eurostat's (i.e., statistical office of the European Union) latest population projection scenario shows that the share of those over age 65 is expected to rise to 28.4% in 2060. Consequently, the old-age support ratio (e.g., the number of persons aged 15-64 years per person aged 65 years or over) declines, which has important implications for public health services and health care costs (Eurostat, 2014b). The abovementioned process of 'graying' is accompanied by 'silvering', also known as the phenomenon '**double graying**'. More specifically, the percentage of older adults aged 80 and older is

growing even stronger. Over the same period (from 2013 to 2060), the share of people ≥80 years is expected to increase from 5.1% to 11.8% (Eurostat, 2014b).

Figure 1. Population pyramid of the European Union: 2008 data and 2060 projection



Note. Source: Eurostat, 2014b

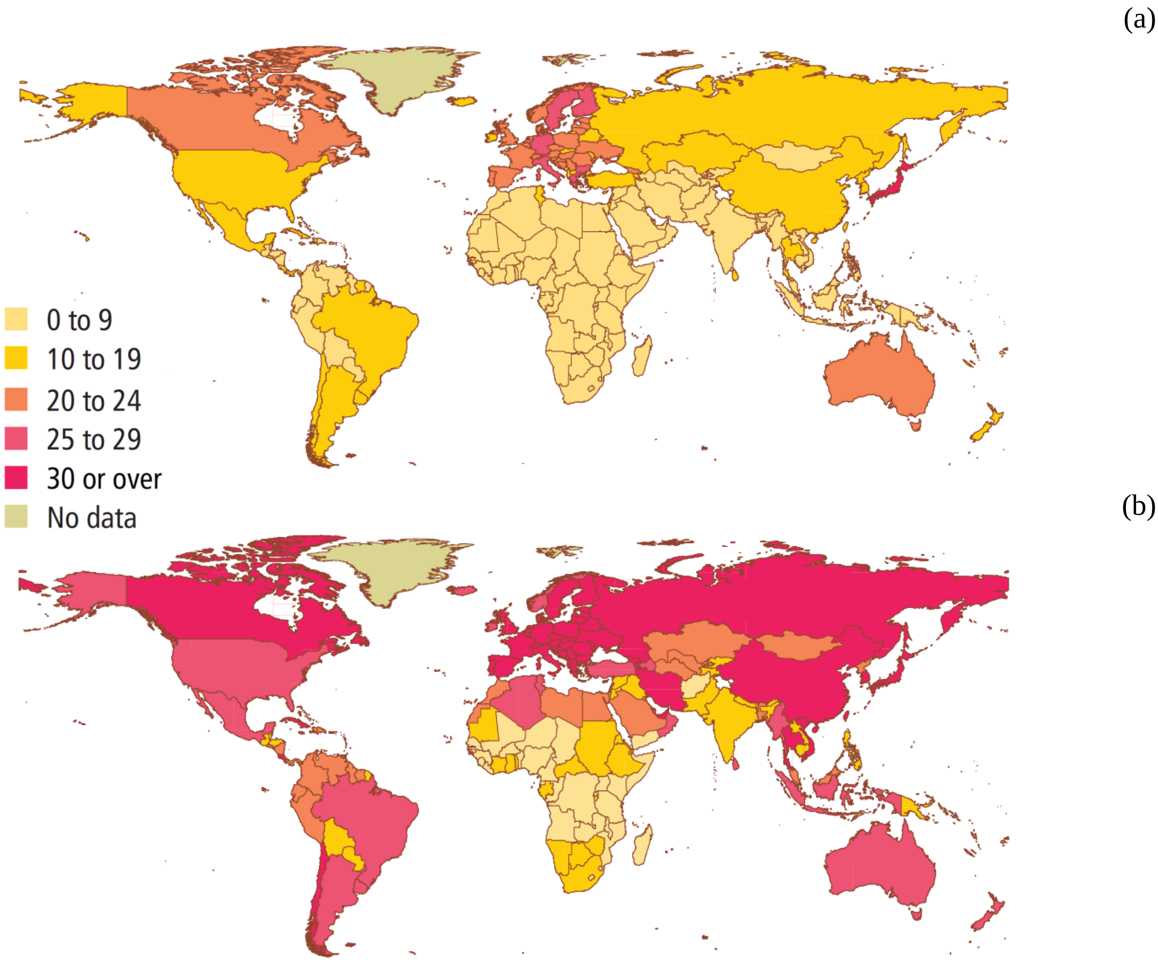
The aging-trend is seen worldwide (*Figure 2*). Aging is evolving fast in the developed countries, although less developed regions will experience an even faster aging over a short period of time (United Nations - Department of Economic and Social Affairs - Population Division, 2012; World Health Organization & US National Institute of Aging, 2011).

It should be noted that the majority of older persons are women. In Europe, the population older than 65 years consisted of 57% women in 2013. Moreover, the **sex-ratio** - the number of men per 100 women - is lower the older the age group (United Nations - Department of Economic and Social Affairs - Population Division, 2012). More specifically, in Europe, the sex-ratio among people aged 60 years or over is 72 men per 100 women, whereas the sex-ratio among people aged 80 years or over is 49 men per 100 women.

1.3. Age categories

It is important to know to who is referred to when the terms ‘older adults, ‘elderly’, or ‘the old’ are used in literature. The following age categories for older adults are most frequently used by gerontologists: the ‘middle aged’ (i.e., those between 45-64 years of age), the ‘young old’ (i.e., those between 65-74 years), the ‘**old**’ (i.e., those between 75-84 years), the ‘**old-old**’ (i.e., those between 85-99 years) and the ‘oldest-old’, those being 100 years and older (Taylor & Johnson, 2008). The present dissertation will especially focus on the old and old-old, because the percentage of older adults aged ≥80 years is growing fast and most previous studies concerning objective assessment and promotion of PA were performed in the younger old and community-dwelling part of the population.

Figure 2. Percentage of the total population aged 60 years and over in 2012 (a) and 2050 (b).



Note. Source: United Nations - Department of Economic and Social Affairs - Population Division, 2012

2. IMPACT OF AGING

The aging of the population is an indicator of improved health conditions and should be seen as a success story. However, it is also one of the main challenges that the world is facing as there is a growing need to prevent age-associated declines and diseases and to provide long-term care. The aging process has an influence on both the individual and the society.

2.1. Age-related diseases and declines in function

Human aging is characterized by changes in structure and functioning of the following body systems: cardiopulmonary system, muscular and skeletal system, sensory system, metabolic system, and nervous system (Mitchell et al., 2012; Spirduso, Francis, & MacRae, 2005). When we take a closer look to the **muscular system**, aging is accompanied with declines in muscle mass and muscle strength (Mitchell et al., 2012). Declines in muscle strength have been associated with reduced mobility and increased risk of falling in older adults (Lauretani et al., 2003; Macrae, Lacourse, & Moldavon, 1992; Marsh et al., 2011; Yang et al., 2014). Therefore, muscle strength will be of particular interest in the present dissertation.

The abovementioned physiological changes can also lead to chronic diseases. Although chronic diseases affect people of all ages, the risk of chronic illness increases with age (Centers for Disease Control and Prevention, 2003). The World Health Organization (WHO) defines chronic diseases as 'diseases of long duration and generally slow progression' (i.e., heart disease, cancer, diabetes, osteoporosis, COPD, etc.). These long-term health problems can lead to limitations in daily life activities, often reducing quality of life and independence of older adults.

2.2. (In-) Dependence

The older population is highly heterogeneous, especially with respect to their level of functionality and consequently with respect to their level of independence. To meet the diversity of needs among older adults, there are several housing facilities. **Housing** depends on (social) preferences and the older adult's specific needs and personal requirements. Some older adults want to stay in their home for as long as possible, while others prefer a group setting. When an older adult needs assistance with daily activities and health care, he/she may require a different type of housing than an older adult who can live independently.

In the present dissertation, three major types of housing options for older adults will be included: the community, assisted living facilities and nursing homes. The term 'residential care facilities' refers to both assisted living facilities and nursing homes. In Flanders, there are 557 registered assisted living facilities and 777 registered nursing homes. This corresponds with a total of 18.232 older adults living in an assisted living facility and 74.159 older adults living in a nursing home (Agentschap Zorg en Gezondheid [Agency for Care & Health], 2010).

2.2.1. Assisted living facilities

Over the last two decades, assisted living facilities have rapidly emerged as housing option for older adults (Agentschap Zorg en Gezondheid [Agency for Care & Health], 2010; Schulz et al., 2006). It is an alternative long-term care option drawing relatively healthier older adults away from nursing homes. Assisted living combines independence with personalized supportive care to meet the needs of older adults in daily life activities. In assisted living facilities, residents are often close to or just entering the early stage of physical impairments (Giuliani et al., 2008). This population is of particular interest for PA promotion because regular PA can slow down the disablement process (Tak et al., 2013) (**CHAPTER 3**).

2.2.2. Nursing homes

The demand for nursing home care is also increasing because of the increased life expectancy. A nursing home is a housing option for older adults who can no longer be cared for at home or in a community-based facility. In this long-term care facility, supervision is provided 24 hours/day. In Flanders, 0.89% of those being 65-74 years, 3.23% of those being 75-79 years and 8.30% of those being 80-84 years, are living in a nursing home. In the present dissertation, the term 'institutionalized older adults' will be used for those older adults living in a nursing home.

2.3. Predictors of functionality

It is important to determine which physical characteristics are significant determinants of functional deterioration in older adults, as this will eventually lead to a loss of independence and institutionalization, and an increase in healthcare costs (den Ouden et al., 2011). Identifying predictors of decline in functional performance is useful for prevention as well as better understanding of the disablement process.

As discussed above, aging is associated with a significant decrease in **muscle strength**. Cross-sectional studies showed that the decline in muscle strength starts from about 50 years of age at a rate of 12-15% per decade. However, greater strength losses have been suggested from longitudinal studies (Hurley, 1995). Von Haehling, Morley and Anker (2010) stated that muscle strength declines by 1.5% between ages 50 and 60 and by 3% thereafter. Women have, on average, 30-40% less muscle strength in comparison with men.
Muscle strength has been identified as a significant predictor of numerous health outcomes such as mortality and disability. A review by den Ouden et al. concluded that significant associations exist between handgrip strength and upper and lower body strength on the one hand, and the probability of disability on the other hand (den Ouden et al., 2011). Declines in muscle strength have been associated with greater impairment of (instrumental) activities of daily living in community-dwelling older adults (Lauretani et al., 2003; Macrae, Lacourse, & Moldavon, 1992; Marsh et al., 2011; Yang et al., 2014). Lauretani et al. showed that handgrip strength, knee extension torque and lower extremity muscle power were strong predictors of poor mobility, defined either as walking speed <0.8 m/s or the inability to walk at least 1 km without difficulty (Lauretani et al., 2003).

Individuals at risk for functional limitations need to be identified, especially those older adults at an early stage of decline. This is important as older adults with early declines in functional performance probably benefit the most from interventions that counteract declines. Prevention of further loss in muscle strength rather than treatment is desirable.

Considering the association between muscle strength and functional performance, **screening** for functionally relevant muscle weakness, based on specific cut-off values, can be crucial in developing targeted interventions to prevent or at least delay functional decline in the aging population and will be the main focus of **CHAPTER 2**.

3. HEALTHY AGING AND PHYSICAL ACTIVITY

As populations around the world are aging rapidly, 'healthy aging', or '**active aging**' has become an important issue in public health research and policy. The WHO states: "Active aging is the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age". Active aging depends on a variety of modifiable and non-modifiable influences. One of those modifiable determinants is PA. Participation in regular PA can contribute to active aging as it prevents disease and functional decline, extends longevity and enhances one's quality of life (World Health Organization, 2002).

3.1. Definition of physical activity

PA can be described as follows: "any bodily movement produced by skeletal muscles that results in energy expenditure (EE)" (Caspersen, Powell, & Christenson, 1985). PA is not the same as exercise. **Exercise** is planned and structured, and only a subcategory of PA. PA can be described in terms of frequency, intensity, duration (time), and type (Ettinger, Wright, & Blair, 2006). When we take a closer look to **intensity**, classifications of light (i.e., walking slowly), moderate (i.e., swimming, gardening, walking briskly, dancing) and vigorous (i.e., running) intensity PA are frequently used. Moreover, metabolic equivalents (MET-values) are often applied to indicate a specific level of intensity: light = <3MET; moderate = 3-6MET and vigorous = >6MET (Haskell et al., 2007).
When exercising, the Borg rating of perceived exertion can be used to rate exercise intensity (Borg, 1998). Participants must pick a number that best describes their feeling of how hard they exercised. The categorical Borg scale ranges from 6 to 20, with 6 indicating the least amount of effort and 20 indicating maximal exertion. An activity that feels 'somewhat hard' corresponds to 13 on the Borg scale.

3.2. Physical activity improves quality of life

Older men and women who are more physically active have lower rates of **chronic diseases** compared to less active individuals (Manini et al., 2006; Taylor & Johnson, 2008). More specifically, a physically active lifestyle reduces the risk for cardiovascular disease, high blood pressure, type 2 diabetes, stroke, cancer, osteoporosis, and sarcopenia (Jones & Rose, 2005). Moreover, previous studies have shown that regular PA improves **physical fitness**. Being physically fit has been defined as "the ability to carry out daily tasks with vigor and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies" (Caspersen, Powell, & Christenson, 1985). Physical fitness can be either health-related (i.e., cardiorespiratory endurance, muscular endurance and strength, body mass and composition, and flexibility) or skill-related (i.e., agility, balance, coordination, speed, power, reaction time), and can be measured with specific tests (e.g., 6 minute-walk test (6MWT), handgrip test) (Caspersen, Powell, & Christenson, 1985; Jones & Rose, 2005; World Health Organization, 2010). Therefore, PA has been associated with higher levels of functional health and a lower risk of mobility problems, falling and fractures. It should be noted that PA has not only been associated with physical health benefits. PA has also been found to positively influence **psychological well-being**. Regular PA has positive effects on mental well-being, decreasing the risk for cognitive impairment, stress, anxiety, depression, and loneliness (Jones & Rose, 2005; World Health Organization, 2010).

3.3. Physical activity recommendations

PA prevents and slows down the disablement process that leads to independence and increased health care cost in the aging population (Tak et al., 2013). The promotion of PA has been identified as public health priority in older adults. As suggested by WHO, older adults (≥65 years) should accumulate at least 150 minutes of moderate intensity aerobic PA or accumulate at least 75 minutes of vigorous intensity aerobic PA throughout the week. Combinations of moderate and vigorous intensity activity can be performed to meet this recommendation. For additional health benefits, older adults should increase their moderate-intensity aerobic PA to 300 min/week or their vigorous-intensity aerobic PA to 150 min/week. The aerobic physical activities should be performed in bouts of at least 10 minutes and to enhance balance and prevent falls, PA should be performed on ≥3 days per week. In addition, WHO states that muscle strengthening activities should be performed on ≥2 days per week. However, if chronic conditions or functional limitations preclude older adults to meet the recommended minimum amount of PA, they should be as physically active as their abilities and health conditions (World Health Organization, 2010). More specific recommendations of the American College of Sports Medicine (ACSM) with respect to endurance exercise state that older adults should accumulate at least 30 or up to 60 min/day in bouts of at least 10 min for moderate-intensity activities (to total 150-300 min/week), or at least 20 or up to 30 min/day of continuous activity for vigorous intensity activity (to total 75-150 min/week). As recommended by ACSM, intensity and duration should be low at the start for those older adults being highly deconditioned, functionally limited or having chronic conditions that affect their physical ability. The progression in duration or intensity should be individual and tailored to tolerance and preference (Chodzko-Zajko et al., 2009; Mazzeo et al., 1998).

3.4. Physical inactivity and sedentariness

Despite the abovementioned evidence, a large proportion of the older population is not regularly involved in PA (Gisle et al., 2010; Philippaerts et al., 2006; Varo et al., 2003). Moreover, total daily activity declines rapidly with increasing age in older adults (Buchman et al., 2014). It should be noted that, next to physical inactivity (i.e., the absence or insufficient amounts of PA), sedentary behavior is an important issue. **Sedentary behavior** is defined as the time spent in a sitting or lying posture characterized by little physical movement and where little energy is being expended (i.e., reading a book, watching TV, driving) (Sedentary Behaviour Research Network, 2012; Tremblay et al., 2010). Research showed a higher prevalence of sedentary lifestyle among older individuals (Varo et al., 2003). Moreover, institutionalized older adults spend 70%–80% of their waking hours being sedentary or performing only light-intensity PA (MacRae et al., 1996). In addition, Owen et al. (2010) stated that "too much sitting is distinct from too little exercise*"*. It is possible for individuals to meet the PA recommendations, yet to be highly sedentary. This phenomenon is also known as the "**active couch potato phenomenon**" (Owen et al., 2010).

Independent of the level of moderate to vigorous intensity PA, sedentary behavior has been identified as an important health risk factor. There is a growing evidence linking sedentary behavior to obesity, cardiovascular and metabolic diseases, cancer and psychosocial problems (Tremblay et al., 2010). It is associated with deleterious health outcomes, which can differ from those that are attributed to a lack of moderate to vigorous PA.

4. PHYSICAL ACTIVITY MEASUREMENT

Accurate quantification of both PA and sedentary behavior is important to researchers and practitioners interested in screening, goal setting, and program evaluation (Berlin, Storti, & Brach, 2006; Tudor-Locke, 2002). Next to subjective measures of PA, objective measures have gain widespread recognition. The purpose of the following paragraphs is to discuss the use of both measures in the old and old-old.

4.1. Subjective measurement of physical activity

The most frequently and widely used methods of assessing PA, are self-report instruments (e.g., PA diaries, questionnaires). These self-reported measures have several **advantages**. They have (1) a low cost, are (2) easy to administer and can collect (3) information on type and context of PA (i.e., walking during leisure time or for transportation) from (4) a large number of people. Moreover, as questionnaires depend on recall, they have (5) no influence on the behavior under study (Sallis & Saelens, 2000). However, self-reports also have some **limitations**. (1) Social desirability can cause over-reporting of PA (Adams et al., 2005). Moreover, (2) poor recall ability, (3) poor ability to judge frequency, duration and intensity of activity bouts and (4) differential interpretation of ‘light’, ‘moderate’ and ‘vigorous’ PA by participants and researchers can cause biases (Montoye HJ, 1995; Sallis & Saelens, 2000). In addition, self-reports do not capture (5) activity patterns throughout the day and (6) unstructured light intensity PA (e.g., ambulatory activity, walking) (Tudor-Locke & Myers, 2001). Limitations (2) and (6) can be of particular interest for older adults. (2) As life expectancy increases, an increasing number of the old and old-old experience cognitive impairments. Self-report measures can be influenced by problems with memory and cognition (i.e., dementia). (6) In addition, older adults tend to engage most frequently in light intensity PA. The old and old-old do not perform a lot of structured PA and engage in PA on a somewhat irregular basis. This also complicates the ability to recall PA.

Despite their limitations, the use of PA questionnaires remains popular because of their abovementioned benefits.

4.2. Objective measurement of physical activity

Recently, more attention has been paid to motion sensors, i.e., pedometers, accelerometers and multisensors, to provide objective measures of structured and ambulatory PA (Tudor-Locke & Myers, 2001). PA monitors have evolved over the years and have become more sophisticated (Bassett & John, 2010). However, the objective assessment of PA remains a challenge in the older population, considering the slow walking speeds and frequent use of walking aids (Clarke et al., 2009).

4.2.1. Pedometers

Pedometers are small, light weight instruments that are typically worn at the waist and that count steps. Pedometers have gained widespread recognition, especially with the growing use of step count goals (Tudor-Locke, 2002). Many studies have investigated the validity of a range of pedometers and revealed marked differences in accuracy, cost and technology (Crouter et al., 2003; Schneider et al., 2003). Two major electronic pedometers can be distinguished (*Figure 3*): (1) pedometers operating on a horizontal, spring-suspended lever arm (pendulum) and (2) pedometers using an accelerometer-type mechanism with a piezoelectric crystal.

(1) The horizontal lever arm in **spring-suspended** pedometers moves up and down with vertical accelerations of the hip (i.e., a step). This opens and closes an electrical circuit. When the lever arm makes an electronic contact, one step is recorded (*Figure 3*). Electronic pedometers are considered to be more accurate than their mechanical predecessors. However, in order to detect vertical accelerations and record a step, a certain force is needed as this pedometer uses a sensitivity threshold (Tudor-Locke, 2002). If the lever arm is not displaced sufficiently, for example with slow and shuffling walking in older adults, no step will be recorded. An additional disadvantage of this electronic

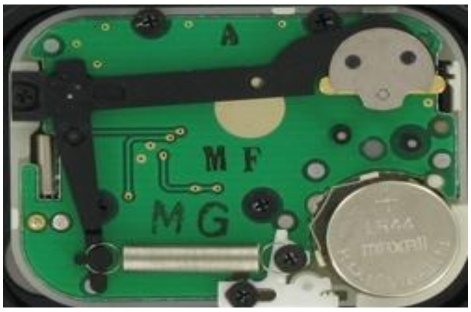
pedometer is that the position of the pedometer must be correct. Tilting or wearing the pedometer at an angle will affect the accuracy.

(2) **Piezoelectric** pedometers use an accelerometer-type mechanism with a horizontal beam and a piezoelectric crystal (*Figure 3*) (Bassett & John, 2010). An accelerometer is a mechanism that measures accelerations of the body. Due to acceleration, a piezoelectric crystal compresses and generates an electric voltage. Voltage oscillations are used to record steps by counting peaks or zero crossings of the acceleration versus time curve. More specifically, the horizontal cantilevered beam is attached to a support at one side that contains a piezoelectric element and a mass. When acceleration is detected by the mass, it causes the piezoelectric element in the beam to bend (inertion) and record a voltage signal. The amplitude of the voltage signal is proportional to the acceleration detected (Garatachea, Torres, & Gonzalez, 2010). An advantage of such piezoelectric pedometers is that these pedometers can determine the magnitude of the vertical accelerations. Previous studies have shown that piezoelectric pedometers should be preferred to spring-levered pedometers because they are more sensitive and because they do not depend on an all-or-none response to record a step (Crouter et al., 2003; Melanson et al., 2004). Another advantage is that the device may be worn at another position than the hip. However, the piezoelectric pedometer must be positioned in such a manner that it stays upright because it can only measure linear acceleration and deceleration. If the device is tilted, the accuracy is reduced. Differences in body shape and how the device is attached to clothing can influence the tilt angle (i.e., deviation away from or toward the body). The maintenance of an upright position of the pedometer at the waist can be a problem for older adults, as intra-abdominal fat tends to increase with aging (Spirduso, Francis, & MacRae, 2005).

It should be noted that, next to a piezoelectric accelerometer, also piezoresistive (using piezoresistors in a cantilever beam and the mass) and differential capacitive accelerometers (displacement of the mass is measured capacitively as the mass is encapsulated between two electrodes) exist. These accelerometers will not be discussed in detail, as the pedometer used in **CHAPTER 1** contains a piezoelectric mechanism.

Figure 3. (a) Internal mechanism and (b) example of a spring-suspended pedometer (left) and piezoelectric pedometer (right)

(a)



(b) Yamax pedometer, model SW-200 New Lifestyles pedometer, model NL-2000

Note. Source: New Lifestyles Inc, 2015

4.2.2. Accelerometers

Although step counting is cheap and relatively simple, it does not reflect the intensity of the movement (Tudor-Locke & Myers, 2001). Accelerometry is preferred because acceleration is proportional to the external force. Therefore, unlike pedometers, summed accelerations from accelerometers (e.g., counts) can reflect frequency and intensity (sedentary, light, moderate or vigorous) of movement over time.

Accelerometers can detect movement in one plane or up to three planes and are classified as **uniaxial, biaxial or triaxial** accelerometers (*Figure 4*). To measure acceleration, these devices use different sensor technologies, such as piezoelectric sensors (as described in 4.2.1.) or sensors to measure change in capacitance (Andre & Wolf, 2007). Uniaxial accelerometers typically contain a lever arm with a sensor sensitive to distortions in the vertical plane (up and down) (Tudor-Locke, 2002). Triaxial accelerometers record acceleration by 3 different accelerometers positioned at 90 degrees from each other. A review by Van Remoortel et al. (2012) showed that triaxial devices are more accurate than uniaxial or biaxial devices.
An accelerometer sensor converts movements into electrical signals that are proportional to the force producing motion. These signals are converted into activity counts. As a result, the activity counts represent the estimated frequency and intensity of movement during a specific time set (i.e., one-

minute time intervals) (Andre & Wolf, 2007; Berlin, Storti, & Brach, 2006; Tudor-Locke, 2002). As the activity can be broken down minute by minute, daily patterns of PA can be established. Moreover, time spent in various intensities (light, moderate, vigorous) can be obtained as the accelerometers records time and intensity. Count values are specific for each type of accelerometer. Therefore several regression equations for specific activities (i.e., walking, running) have been developed to translate these raw data (counts) into more meaningful units (i.e., EE or METs) via computer analysis. The variation of the electrical signal is utilized to select an appropriate regression equation. One disadvantage is that these equations have been developed for specific activities (e.g., walking and running) and do not estimate other activities (i.e., biking) accurately. Moreover, sometimes equations are proprietary.

An advantage of accelerometry is that PA can be reported in different ways: total counts/steps over a period of time, counts/steps per minute, minutes spent in specific activity intensities, estimates of EE. However, a limitation is that some accelerometers are subject to motion from activities such as driving in a car (Andre & Wolf, 2007).

Figure 4. Example of an uni-, bi- and triaxial accelerometer.

Uniaxial Caltrac | ***Biaxial** BioTrainer* | ***Triaxial** Actigraph GT3X*

4.2.3. Multisensors

Although accelerometers reflect the frequency, the intensity and the duration of an activity, they cannot differentiate between sitting still and standing still, or between non-wear time and sedentary behavior. Consequently, the definition of non-wear time can have a large impact on the estimates of sedentary time by an accelerometer (Masse et al., 2005). Therefore, these devices only provide an estimate of lack of movement, rather than time spent in sedentary behavior.

Nowadays, accelerometers are sometimes complemented by other bodily information (heart rate, temperature, etc.) in multisensors. The use of multisensors such as the **Sensewear** Armband (SW; BodyMedia, Inc., Pittsburgh, PA; *Figure 5*), has gained widespread recognition. Multisensors have been shown to provide more accurate estimates of EE than accelerometry alone (Van Remoortel et al., 2012). When we take a closer look to the SW, the device combines accelerometry with noninvasive physiological sensors that measure conductivity, skin temperature, and heat dissipating from the body (*Figure 5*). The device estimates EE minute-by-minute through pattern recognition algorithms and exercise-specific formulas to estimate EE from all sensor signals (Andre & Wolf, 2007).

Figure 5. The Sensewear Mini.

Note. Source: BodyMedia, 2013

4.3. Criterion measures of physical activity

The validity of objective measures of PA should be tested against a criterion measurement. Different criterion measures are available to validate several parameters of PA (i.e., steps, EE). The criterion method for step counts is observation. Actual steps can be hand tallied with a hand counter. For EE, direct or indirect calorimetry can be used. Direct calorimetry measures total heat loss from the body. However, this method is not frequently used, because of practical limitations. **Indirect calorimetry**, such as (1) Doubly labeled water and (2) open/closed circuits, is based on the measurement of oxygen(O_2)-consumption and carbon dioxide(CO_2)-production.

(1) **Doubly labeled water** is free-living indirect calorimetry and involves the ingestion of water (H_2O) labeled with two stable isotopes, namely hydrogen/deuterium (^2H) and oxygen (^{18}O). As energy is expended, CO_2 and H_2O are produced: ^8O is eliminated as CO_2 and H_2O, while ^2H is eliminated from the body as H_2O. The rate of CO_2-production, and thus EE, is calculated from the difference between

the isotope elimination rates (Andre & Wolf, 2007). However, this method is not suitable for large-scale studies, because of its high cost, specialized equipment and complexity of analyses (Ainslie, Reilly, & Westerterp, 2003).

(2) **Metabolic systems with open or closed circuits** measure EE via pulmonary gas exchange. The usefulness of closed circuits (no outside air enters the system) during exercise is limited, as this technique can cause airway resistance. Moreover, during strenuous exercise the production of CO_2 is high, and participants have to absorb large volumes of CO_2. For open circuits, the subject inhales ambient air. One example is the Douglas bag method, but now, more sophisticated systems are used (Ainslie, Reilly, & Westerterp, 2003). These devices measure the O_2-consumption and CO_2-production and indirectly compute the calories burned during the period of measurement, using for example the Weir formula: EE=[(3.9 x VO_2) + (1.1 x VCO_2)] (Weir, 1990). This method is normally performed under laboratory conditions. However, more recently, portable metabolic systems have become available (i.e., Oxycon Mobile; CareFusion Respiratory Care, Yorba Linda, CA) (Andre & Wolf, 2007; Hannink et al., 2010).

5. INTERVENTIONS TO PROMOTE PHYSICAL ACTIVITY IN OLDER ADULTS

Measures of PA can be useful for screening and goal setting, but also for program evaluation. As discussed above, objective and subjective measures can be used to quantify changes in PA behavior. The promotion of a physically active lifestyle has become a public health priority as a large proportion of the older population is not regularly involved in PA. Different reviews suggest that interventions designed to increase PA behavior among older adults can be effective (Chase, 2014; Conn et al., 2003; King, Rejeski, & Buchner, 1998; van der Bij, Laurant, & Wensing, 2002).

The number of PA intervention studies in older adults is rapidly accumulating, although few interventions targeted specific subgroups of older adults. In 2010-2011 a study was conducted under the authority of the **Flemish Government** regarding the availability of attractive and adapted sports and exercise programs for older adults in Flanders, Belgium (Delecluse, Theeboom, Westerbeek, Martien, & Verheyden, 2012). After having consulted both older adults as well as representatives of the major sports federations and related organizations for older adults in Flanders, it was noted that the existing programs did not sufficiently take account of differences in age, level of functional fitness and social context. It was therefore concluded that actual programs target most often the younger, the fit and the community dwelling part of the population, while ignoring specific needs of other older adults. It is thus crucial to develop specific programs that are adapted to the fitness and functionality level of target groups within the older population that are currently ignored.

In the following paragraphs, several important aspects associated with a successful PA intervention will be discussed. In order to conduct optimal interventions and programs in the old and old-old, on should consider the cost-effectiveness of the intervention. Moreover, taking into account barriers and motivators for being physically active, and the use of a theoretical framework can enhance the effectiveness of an intervention. Finally, ergometer cycling will be put forward as a feasible type of PA in the old and old-old.

5.1. Cost-effectiveness of physical activity interventions

Traditional structured interventions, with strict supervision, have the advantage that the amount and quality of training can be controlled. However, their implementation possibilities are limited because they require a lot of organization, time and support. Moreover, it is not clear whether positive effects can be maintained in the long-term, in the absence of supervision (Conn et al., 2003; Taylor et al., 2004; van der Bij, Laurant, & Wensing, 2002). In order to have a public health impact, PA interventions should not only be efficacious, they should also be implemented on a **large scale**. When developing an intervention one should take implementation possibilities into account, given that the financial resources for PA promotion are often restricted (Hanson et al., 2014).
To facilitate PA promotion in the wider community, the effectiveness of less time-consuming counseling procedures should be studied. For example, minimal-contact coaching, consisting of a limited number of contact moments between a PA coach and participants, has shown to be effective in older adults (Opdenacker et al., 2008; Van Hoecke et al., 2014).

5.2. There is nothing more practical than a good theory

Efficacy and implementation possibilities do not always go hand in hand. Different reviews suggest that interventions using counseling procedures with a theoretical basis tend to show larger effects than non-theoretically based interventions (Chase, 2014). A variety of theoretical models have been used in the development of PA interventions. In the past decade, the **Self-Determination Theory** (SDT) has become the dominant theoretical approach to facilitate behavioral change, and in particular to increase PA (Chatzisarantis & Hagger, 2009; Deci & Ryan, 1985). This theory assumes that people possess three psychological needs; the need for competence, the need for relatedness and the need for autonomy (Ryan & Deci, 2000). (1) The **need for competence** reflects the desire to experience mastery and success. This need can be fulfilled by providing structure, positive feedback and optimal challenges (appropriate goal setting). The coach can identify barriers and draft a plan to solve them (Patrick & Williams, 2012). (2) The **need for relatedness** reflects the desire to feel connected with others, to experience supportive relationships. A coach can fulfill this need by creating meaningful relationships between the coach and participants or between significant others and participants. The coach expresses empathy and acceptance towards the participants and avoids judgment or criticism

(Patrick & Williams, 2012). (3) The **need for autonomy** reflects the desire to be the origin of your own behavior. This need can be supported by providing choices, exploring options with the participants, and letting the participants make decisions. Moreover, the coach focuses on task-oriented rather than ego-oriented goals and uses autonomy-supportive language (e.g., using 'could' instead of 'should'). The three needs are considered fundamental to be motivated in PA engagement. The needs influence the degree to which an individuals' behavior is internalized. The more a behavior is internalized, the more the individual is assumed to be autonomously engaged in a behavior. Therefore, need-supportive environments foster self-determined motivated behavior, which is assumed to yield more (long-term) engagement in behavioral change (Ryan & Deci, 2000; Teixeira et al., 2012). Long-term engagement is important as it is not clear whether the positive effects of traditionally supervised PA interventions can be maintained in the long run, when supervision is no longer available (Conn et al., 2003; Taylor et al., 2004; van der Bij, Laurant, & Wensing, 2002).

The SDT may be of particular interest in the older population, as older adults often perceive lower levels of competence (need for competence) and a lower sense of personal control (need for autonomy) (Mirowsky, 1995; Parisi, 2010). Furthermore, aging is often associated with loneliness and social isolation (need for relatedness). SDT-based PA interventions have been successfully applied in community-dwelling older population (Van Hoecke et al., 2014). However, to our knowledge no studies to date have incorporated SDT-principles in the old and old-old.

5.3. Physical activity determinants in older adults

In order to conduct optimal interventions and programs, the determinants of PA and exercise should be taken into account. Baert et al. (2011) categorized **barriers and motivators** for PA in intrapersonal, interpersonal and community factors according to the Social-Ecological framework. *Table 1* depicts the major motivators and barriers for PA in the old and old-old and is based on the reviews by Baert et al. (2011) and Chen et al. (2010).

Table 1. Motivators and barriers for physical activity in older adults.

Intrapersonal level
- Physical health conditions
- Physical and psychological health benefits
- Fears (e.g., fear of falling or injury, fear for exercising outside)
- Lack of time/motivation/interest
- Self-efficacy
- Past sedentary lifestyle
- Insufficient understanding about PA
Intrapersonal level
- Social support (e.g., encouragement)
- Exercise companion
- Social opposition (e.g., being told that PA is inappropriate)
- Professional advice (e.g., advice from health care provider)
- Care of significant others
Community level
- Nature of the exercise program (e.g., difficulty level, training frequency, home-based or group-based)
- Costs (e.g., high subscription cost)
- Time constraints (e.g., time of classes)
- Weather conditions
- Environmental conditions (e.g., safety, accessibility)
- Transportation facilities

When a PA intervention or activity program is developed for the old and old-old, the activity should be adapted to the target population, as the activity may not be too difficult and must be perceived as safe. The promotion of PA in older adults will generally place less emphasis on attaining high volumes of activity, or engaging in vigorous-intensity activity as exercise capacity (i.e., physical fitness) is lower in older adults than in younger persons. However, the health status and abilities of older adults vary widely, and some older adults are capable of performing high volumes of moderate- and vigorous-intensity activity (World Health Organization, 2010).
In addition, older adults often indicate to have a lack of motivation and interest, therefore an appropriate activity should be chosen taking into account older adults' preferences. An appropriate activity, challenging participants' skill and experience level can also stimulate feelings of competence (Patrick & Williams, 2012). Hanson et al. (2014) stated that finding individual motivations (linked to personal history and previous hobbies) in older adults living in assisted living facilities was often

helpful in increasing engagement. The two most practiced physical activities by older adults (≥55 years) in Flanders/Belgium are cycling and walking. Cycling and/or walking was performed by 4 out of 10 older adults in the past 12 months (Scheerder et al., 2011). In **CHAPTER 3** of the present manuscript, ergometer cycling was included for the promotion of PA in older adults.

5.4. Cycling in older adults

Most older adults have experience with outdoor cycling, as cycling was a major mode of transportation when they were younger. In the intervention study in assisted living facilities (***Paper 4***) data revealed that 96.4% of the older adults (mean age 82 years) used to cycle outdoors (data not published). However, they stopped riding the bicycle because of the following reasons: (1) problems with balance and skills required to handle a bicycle, (2) occurrence of a fall or the fear of falling, (3) vision problems, (4) dangers of the road and traffic, (5) pain, and (6) bad weather. Given these reasons for not cycling outdoors, **ergometer cycling** might provide a feasible type of PA in this population (Ettinger, Wright, & Blair, 2006). Indoor cycling requires only a minimum fitness level and skill level, and participants do not have to worry about traffic, safety or weather. Moreover, it involves low impact movement, as it is a non-weight-bearing exercise. These are important issues as 'physical health conditions' was identified as an important barrier for PA (see 5.3.). Older adults, particularly those with existing health issues can be hesitant to engage in PA. In addition, there is a high risk and fear for injury and falls in the old and old-old (Murphy, Williams, & Gill, 2002).

Cycling trains the cardio-respiratory system and lower body muscles, which are important for many daily life activities (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002). As discussed above (see 2.3.) lower body muscle strength has been associated with functional performance. Moreover, muscle weakness of the legs is frequently found to be a risk factor for falls in older adults (Macrae, Lacourse, & Moldavon, 1992).

Different studies have revealed positive effects of short-term cycle ergometer interventions in older adults. Buchner et al. (1997) showed an increase in leg strength, whereas Denison et al. (2013) showed an increase in functional performance (e.g., Time Up and Go test). Moreover, improvements in gait (e.g., step time and step length) (Lee & Cho, 2014), and exercise capacity (i.e., VO_2max) (Buchner et al., 1997; Pogliaghi et al., 2006) were found.

6. OBJECTIVES AND GENERAL OUTLINE OF THE THESIS

Based on the abovementioned aspects, the present doctoral thesis consists of 3 interrelated chapters regarding objective assessment and promotion of PA in older adults, with specific attention for the old and old-old. The promotion of PA in the present dissertation can be seen as (1) an early identification of functional decline (‘screening’) and (2) a strategy to prevent or reverse declines associated with aging (‘intervention’).

CHAPTER 1 investigates the validity (‘assessment’) of two motion sensors (***Paper 1*** and ***Paper 2***) in a sample of institutionalized older adults. **CHAPTER 2** (***Paper 3***) examines the link between muscle strength and functional performance and identifies functionally relevant cut-off values for knee extension strength (‘screening’). Finally, in **CHAPTER 3**, the short- and long-term effects on PA, physical performance and muscle strength of a 10-week cycle ergometer intervention in assisted living facilities (***Paper 4***) will be evaluated (‘intervention’).

The manuscript is a compilation of four scientific papers. The papers are published, accepted for publication (in press) or under review in international peer-reviewed journals. Considering that multiple papers proceeded from the same study sample, there is a partial overlap (especially in methodology) between some papers. The study sample in ***Paper 1*** is the same as in ***Paper 2***. Moreover, the study samples of the first 2 papers and ***Paper 4*** were included in ***Paper 3***.

In the following paragraphs; the context, design and objectives of each chapter are shortly described. In *Table 2*, the outline of the present doctoral thesis is illustrated.

Table 2. Summary of methodology in the different papers.

	CHAPTER 1		CHAPTER 2	CHAPTER 3
	Paper 1	***Paper 2***	***Paper 3***	***Paper 4***
Main goal	Assessment	Assessment	Screening	Intervention
Participants	N=68	N=60	N=947	N=95
Mean age	85.8 ± 5.6 years	85.5 ± 5.5 years	72.6 ± 8.3 years	82.1 ± 5.9 years
Gender	79.4% females	78.3 % females	68.20 % females	76.8% females
Living setting	Nursing homes	Nursing homes	Nursing homes Assisted living facilities Community-dwelling	Assisted living facilities
Intervention conditions				(1) Control group (2) Structured coaching program (3) Autonomy-supportive coaching program
Primary outcomes	Step counts - *Pedometer New Lifestyles 2000* - *Hand counter*	Energy expenditure (kcal/min) - *Sensewear Mini* - *Portable gas analyzer Oxycon Mobile*	Muscle strength (kg/kg BW) - *Handgrip strength* - *Knee extension strength* Functional performance - *6MWD (m) and mPPT (/36)*	Adherence rate Physical activity - *Questionnaires* - *Sensewear Mini and Pro* Muscle strength - *Knee extension strength (kg)* Functional performance - *6MWD (m) and mPPT (/36)* - *step length (cm)*
Secondary outcome measures	Walking speed (km/h) BMI (kg/m²) Walking aids Step length (cm) 6MWD (m)	Walking speed (km/h) BMI (kg/m²) Walking aids		Fall frequency
Clinical trials ID	NCT01621035	NCT01621035	NCT01621035/NCT01748461*	NCT01748461

Note. Abbreviations: BMI = Body mass index; BW = Body weight; 6MWD = 6-minute walk distance; mPPT = modified Physical Performance Test

* Data for this paper were also compiled from 3 other studies: Pelssers et al., 2013; Van Hoecke et al., 2014; Van Roie et al., 2013.

6.1. Chapter 1 - Objective assessment of physical activity in institutionalized older adults

The need for valid tools to measure PA and sedentary behavior has been identified as an important health research objective (Troiano, 2005). In the last decades, both subjective and objective measures of PA have been developed. Self-report diaries and questionnaires are easy to administer, but rely on a person's ability to judge duration, frequency and intensity (Montoye, 1995). Therefore, more attention has been paid to motion sensors (i.e., pedometers, accelerometers, multisensors). These motion sensors are able to capture unstructured activities of light intensity (i.e., activities incorporated in daily life; walking) that are often poorly reported in subjective questionnaires (Ainslie, Reilly, & Westerterp, 2003; Sallis & Saelens, 2000).

Most research on the accuracy of motion sensors focused on the young-old or community-dwelling older population. An important gap in the literature is the limited information on the validity in the old and old-old, especially in institutionalized older adults. This population is of particular interest because of the slow shuffling walking patterns and frequent use of walking aids (Clarke et al., 2009). Moreover, the validity of activity monitors including specific skin sensors (i.e., galvanic skin sensor and skin temperature sensor in the SW) can be influenced by age-related changes in skin and body composition (Baumgartner et al., 1995; Montagna & Carlisle, 1990). More specifically, some of the changes in the skin include a breakdown of collagen and elastic fibers and a decreased activity of the oil and sweat glands. These decreases cause the skin to become dry and less pliable and make it more difficult for older adults to dissipate heat from the body and maintain thermoregulation (Montagna & Carlisle, 1990; Spirduso, Francis, & MacRae, 2005).

Another gap in literature is that limited data exist under free-living conditions (Cavalheri et al., 2011; Langer et al., 2009). Most studies have established the validity under controlled laboratory conditions, using a treadmill or ergometer (Cyarto, Myers, & Tudor-Locke, 2004; Dwyer et al., 2009; Furlanetto et al., 2010; Machac et al., 2013; Marsh et al., 2007; Smith et al., 2012). However, in daily life, motion sensors are subject to other sources of error (i.e., walking speed obtained in a lab may be higher than ambulatory walking speed). In addition, information obtained on a treadmill is difficult to generalize to daily life because of kinematic differences between treadmill and over ground walking (e.g., slower stride rates) and treadmill familiarization is difficult for older adults (Wass, Taylor, & Matsas, 2005). Validation studies performed under free-living conditions, or at least including a simulation of daily activities in a lab setting, provide a better test of validity because the nature of activities is more complex. Furthermore, considering the reduced ability to perform daily activities in old age, the assessment of these activities is of high importance.

Therefore, **CHAPTER 1** of this manuscript aims at validating motion sensors in institutionalized older adults under free-living conditions. The first chapter resulted in two papers: ***Paper 1*** aims at validating a piezoelectric pedometer New Lifestyles 2000 and ***Paper 2*** validates the multisensor Sensewear Mini

(SWMini). The study sample in both papers was the same, as participants were instructed to wear the pedometer and multisensor simultaneously during a standardized protocol lasting 30 minutes. During the protocol, participants had to perform different tasks, representative of some everyday life activities and based on the Glittre Activities of Daily Life test (Skumlien et al., 2006) (i.e., sitting; walking; sitting/standing/walking; moving objects). Participants (mean age=86 years) were recruited between October 2011 and April 2012 in three nursing homes in Belgium.

This validation of motion sensors in the old and old-old (**CHAPTER 1**) can provide valuable information for **CHAPTER 3**. If we want to investigate the effects of an intervention study on PA in assisted living facilities, valid and reliable instruments to measure PA are needed.

6.1.1. Paper 1 – Counting steps in institutionalized older adults during daily life activities: the validation of two motion sensors.

Walking is the primary mode of PA among the older population (Yusuf et al., 1996). Consequently, valid and reliable PA monitors that specifically address walking are needed for this population. The purpose of ***Paper 1*** was to assess the utility of an inexpensive piezoelectric pedometer among nursing home residents. Simultaneously, the multisensor SWMini was evaluated for step counting. A piezoelectric pedometer was used, as this pedometer is considered to be more sensitive to count steps in comparison to a spring-levered pedometer (Crouter et al., 2003; Melanson et al., 2004). Moreover, the piezoelectric pedometer was not only validated at the waist, but also at the ankle. The ankle might be a more suitable location for step counting at slow walking speeds (Bassett & John, 2010; Karabulut, Crouter, & Bassett, 2005; Shepherd et al., 1999). Compared with waist-worn devices, ankle-worn devices are not susceptible to errors due to motion of soft tissue and are more sensitive to movement.

6.1.2. Paper 2 - Energy expenditure in institutionalized older adults: Validation of Sensewear Mini

Next to step counts, EE is a common outcome when assessing PA in daily life in an objective way (Caspersen, Powell, & Christenson, 1985). Indirect calorimetry can be used to assess EE. However, the techniques are relatively expensive and/or require laboratory settings, making them unfeasible for large-scale studies. The purpose of ***Paper 2*** was to examine the validity of the triaxial multisensor SWMini among the old and old-old during rest (i.e., sitting quietly) and during the performance of daily life activities. Multisensors have been shown to provide more accurate estimates of EE than accelerometry alone (Van Remoortel et al., 2012). Moreover, triaxial devices (e.g., SWMini) are more accurate than uniaxial devices for the assessment of active and total EE (Van Remoortel et al., 2012).

The validation of the SW in older adults is also important in the context of evaluating sedentary behavior, as this cannot be measured with a pedometer, nor with an accelerometer.

6.2. Chapter 2 - Muscle strength and functional performance in older adults

CHAPTER 2 focuses on the association between muscle strength and functional performance and resulted in one paper (***Paper 3***). The main goal of **CHAPTER 2** can be situated in the domain of 'screening'. Older adults at risk for muscle weakness, and thus at risk for functional limitations and institutionalization, need to be identified. In this way, targeted interventions can be developed to prevent or at least delay functional decline in the aging population. Moreover, the information gathered in **CHAPTER 2** can help us to design the intervention study in **CHAPTER 3** (e.g., type of physical exercise and target population).

6.2.1. Paper 3 – Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?

Handgrip strength appears to be a good predictor of adverse outcomes such as functional impairment, hospitalization and mortality (Legrand et al., 2014; Sasaki et al., 2007). Even though handgrip strength has been proposed to reflect the overall strength status of an older individual (Visser et al., 2000), differences in activities requiring upper and lower body strength recommend caution when using a single action to describe overall muscle strength (Bohannon, 2008; Bohannon et al., 2012; Felicio et al., 2014). For example, grip strength cannot provide a logical explanation for difficulties with sit-to-stand, which does not include upper body muscles. Bohannon (2009) stated that grip dynamometry can be used to characterize upper limb strength but not lower limb strength. Knee extension dynamometry can be used to characterize limb and trunk strength (Bohannon, 2009).

In addition, although handgrip strength has been reported to correlate well with leg strength, inconsistent findings were reported in older adults. Felicio et al. (2014) found no significant or only poor correlations between performance of knee flexor and extensor muscles determined using isokinetic measures and handgrip strength in community-dwelling elderly women. The older population progressively shows more physical problems and disabilities, and therefore, the relationship between upper and lower body strength may be distorted. Both parameters can reflect different properties in older adults. Moreover, aging is associated with a greater percent decline in lower than in upper limb muscle size and strength (Frontera et al., 2000; Newman et al., 2003; Samuel et al., 2012), which again suggests the importance of measuring lower limb muscle strength.

Lower limb muscle measurements may be a better parameter of mobility outcomes. Visser et al. (2005) reported a significant correlation between lower limb strength and increased risk for mobility loss. It is widely accepted that knee extension strength is of major importance for functional performance (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002). Knee-extension strength has been positively correlated with instrumental activities of daily living in community-dwelling older adults (Kojima et al., 2014). Therefore, the first purpose of ***Paper 3*** was to examine whether knee extension strength, measured using a simple field test, is a good predictor of functional performance in older adults.

As discussed above, it is important to identify persons with muscle weakness. For grip strength, normative data and cut-off values for muscle weakness are available in literature (Alley et al., 2014; Bohannon et al., 2006; Lauretani et al., 2003). Lauretani et al. (2003) determined handgrip strength cut-off values of 30 kg for men and 20 kg for women to discriminate adults with mobility limitations. In a study by Alley et al. (2014) grip strengths of 26-32 kg for men and 16-20 kg for women were classified as ‘intermediate’ weakness (detectable, although less severe weakness) associated with mobility impairment. However, literature lacks data on functionally relevant cut-off values for knee extension strength. Consequently, the second aim of ***Paper 3*** was to identify functionally relevant cut-off values for knee extension strength. Having functional limitations was defined as not being able to walk 400 m during the 6MWT (Morley et al., 2011) and/or having a modified physical performance-score (mPPT) below 32 (Brown et al., 2000; Van Roie et al., 2011). Physical fitness-tests are frequently used to measure functionality. The 6MWT it is easy to apply, well tolerated, and it reflects the activities of daily life. In addition, in a recent study by Vilaça et al. (2013) shorter distance in 6MWT has been associated with lower knee extension strength in a sample of elderly women.

There are different ways to measure muscle strength. Muscle strength is defined as the amount of force that can be produced with a single muscle contraction. Isometric (static) contraction generates force without changing the length of the muscle, whereas isotonic/isokinetic (dynamic) contraction causes the muscle to shorten/lengthen as it causes movement of a body part. To be useful for large-scale screening purposes, the identifications should be based on simple field tests. To date, isokinetic dynamometry is considered as the golden standard for measuring strength in scientific research (Drouin et al., 2004; Osternig, 1986). However, its practical applicability is limited because it is complex, time-consuming and costly. Therefore, in ***Paper 3***, cut-off values for isometric handgrip and knee extension strength are based on a simple field tests. The field test for knee extension strength is based on the knee extension strength test of the Physiological Profile Assessment (Lord, Menz, & Tiedemann, 2003). This static test is time efficient, easy to perform and requires only portable equipment.

Living settings differ from each other in terms of needs related to functionality and dependence (see 2.2.). Moreover, Krol-Zielinska et al. (2011) reported significant differences in PA and physical fitness between the different living settings in older adults. Therefore, following settings were included in ***Paper 3***: community-dwelling older adults, older adults living in assisted living facilities and institutionalized older adults.

6.3. Chapter 3- Interventions to promote physical activity in assisted living facilities

As described in **CHAPTER 2**, aging is associated with significant declines in muscle strength, which increase the probability of disability. Especially lower body muscles are important for many daily life activities (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002). Participation in regular PA can reduce this negative impact of aging. However, a large proportion of the older population is not regularly involved in PA, and PA in older adults declines more rapidly with increasing age (Buchman et al., 2014). Moreover, to the best of our knowledge, only a few PA intervention studies have focused on the effects in assisted living facilities.

Despite the fact that exercise and PA are perceived as highly important by the management of assisted living facilities, most organized activities have a social goal only (i.e., opportunities to be socially connected with other residents) (Hanson et al., 2014). In addition, half of all physical exercise classes are conducted with participants in a seated position (Hanson et al., 2014). The management and staff of the assisted living facilities indicated that PA promotion is not a priority of the facility. They specified that residents have to take initiatives by themselves to be physically active and that the prevention of loneliness and social isolation are more important (data gathered during the intervention study, but not published or included in ***Paper 4***). Nevertheless, Tighe et al. (2008) showed that higher levels of activity are associated with longer retention in the assisted living facility. Consequently, the transition to more intensive and expensive levels of care (e.g., nursing homes) is postponed.

We need to find a compromise between developing highly intense interventions having large effects on biological or behavioral outcomes, which are most often accepted by only few older adults, and developing interventions that are too light to have a real impact (Vellas, Cestac, & Moley, 2012). Moreover, given that financial resources, staffing issues, physical space constraints, limited mobility, diversity of the group, lack of motivation and forgetfulness of the residents are commonly cited obstacles in the promotion of PA in assisted living facilities, we need to take implementation possibilities into account. An adequate balance between scientific evidence (i.e., efficacy) and the possibility to translate research into the wider community (i.e., implementation possibilities) is an important challenge (Hanson et al., 2014).

Because of the abovementioned aspects, the purpose of **CHAPTER 3** was to investigate the effects of a cycle ergometer intervention in older adults living in assisted living facilities. Considering the high risk for injury and falls in this older population, ergometer cycling was chosen, as it involves low impact movement*. Moreover, ergometer cycling trains the cardio-respiratory system and the lower body muscle, which can be important because older adults in assisted living facilities are often close to or just entering the early stage of physical impairments (Giuliani et al., 2008). In addition, the relatively low implementation cost of cycle ergometers can be valuable because of the need to implement PA promotion strategies on a large scale. In ***Paper 4***, the feasibility and short- and long-term effects of ergometer cycling interventions in assisted living facilities were discussed.

*The program is partially based on 'Every Pedal Counts', an initiative from OKRA-Sport. OKRA-sport is a socio-cultural elderly organization in Flanders, Belgium. They developed a 10-week cycle program (individual or in group), consisting of weekly training schedules with several beginning levels for the cycle ergometer and for an outdoor setting (i.e., on the road). It was especially developed to reach fit as well as sedentary older people. It should be noted that no scientific evaluation was performed (OKRA-Sport, 2013).

6.3.1. Paper 4 – Short- and long-term effects of 10-week cycle ergometer interventions for older adults in assisted living facilities

Traditional fitness center oriented PA interventions for older adults are structured and include strict supervision by a PA coach. However, the implementation possibilities are limited because they require a lot of organization and financial support. In order to facilitate PA promotion in the wider community, the effectiveness of less demanding procedures should be studied (see 5.1.). Therefore, the cycle ergometer intervention in ***Paper 4*** compared two coaching procedures: a structured fitness coaching procedure with permanent assistance and strict control of training volume and intensity (≈traditional fitness center oriented program) and a need-supportive coaching procedure with minimal contact and supervision. The minimal contact coaching procedure used SDT-embedded coaching techniques (see 5.2.). Especially the autonomy-component considerably differed between both intervention groups as participants in the autonomy-supportive coaching program had to complete the program on their own and they could choose when and with whom they exercised. To the best our knowledge, no intervention studies have incorporated SDT principles among older adults living in assisted living facilities (Teixeira et al., 2012). The effects on adherence rate, subjectively and objectively assessed PA, functionality and muscle strength were examined post-intervention (10 weeks after pre) and at follow-up (24 weeks after post). Based on the results of **CHAPTER 1**, the SW (Mini and Pro) was used to objectively assess PA in ***Paper 4***.

The four research articles of the present doctoral thesis are included in **Part 2**. **Part 3** comprises the summary and general conclusion. Practical implementations and suggestions for further research will be discussed.

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PART 2

RESEARCH ARTICLES

CHAPTER 1

Objective assessment of physical activity in institutionalized older adults

Paper 1	Counting steps in institutionalized older adults during daily life activities: the validation of two motion sensors
Paper 2	Energy expenditure in institutionalized older adults: Validation of Sensewear Mini

Counting steps in institutionalized older adults during daily life activities: the validation of two motion sensors

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Accepted in *Journal of Aging and Physical Activity*, Epub ahead of print

ABSTRACT

The primary purpose of this study was to assess the validity of two motion sensors in measuring steps in institutionalized older adults during daily life activities. Sixty-eight nursing home residents (85.8 ± 5.6 years) were equipped with a hip-worn and ankle-worn piezoelectric pedometer (New Lifestyles 2000) and with an arm-mounted multisensor (Sensewear Mini). The actual steps were tallied by an investigator with a hand counter. The results revealed that the multisensor and hip- and ankle-worn pedometer significantly underestimated step counts (89.6 ± 17.2%, 72.9 ± 25.8% and 20.8 ± 24.6%, respectively). Walking speed accounted for 41.6% of the variance in percent error of the ankle-worn pedometer. The threshold value for accurate step counting was set at 2.35 km/h, providing percent error scores within ±5%. The ankle-worn piezoelectric pedometer can be useful for accurate quantification of walking steps in the old and old-old walking faster than 2.35km/h.

Keywords: motion sensors; validity; institutionalized older adults; daily physical activity

INTRODUCTION

The fastest-growing segment of the population worldwide is the old-old, i.e., those 85 years and over (Christensen et al., 2009). Aging is associated with a reduction in muscle strength and physical fitness, which contribute to a loss of independence (Spirduso, Francis, & MacRae, 2005). Regular participation in physical activity (PA), both in the old (75–84 years) and the old-old, has been associated with improved quality of life and a decreased risk for disability, morbidity and chronic diseases (Taylor & Johnson, 2008). Walking is the primary mode of PA among the older population (Yusuf et al., 1996). Consequently, valid and reliable PA monitors that specifically address walking are needed for this population.

In the last decades, both subjective and objective measures of PA, including walking have been developed. Self-report diaries and questionnaires are easy to administer, but rely on a person’s ability to judge duration, frequency and intensity (Montoye, 1995). More recently, more attention has been paid to motion sensors, i.e., pedometers and accelerometers. These devices can capture unstructured activities of light intensity that are common in older adults (i.e., walking) and that are often poorly reported on subjective questionnaires (Sallis & Saelens, 2000).

Different studies investigated the validity of a range of pedometers and revealed marked differences in accuracy, cost and technology (Schneider et al., 2003; Schneider, Crouter, & Bassett, 2004). Piezoelectric pedometers, using a piezoelectric crystal to measure acceleration are considered to be more sensitive to count steps in comparison to spring-levered pedometers (Crouter, Schneider, & Bassett, 2005; Melanson et al., 2004; Schneider et al., 2003). However, the objective assessment of walking steps remains a challenge in the older population, with a slow shuffling walking pattern and frequent use of walking aids (Clarke et al., 2009). Grant, Dall, Mitchell, and Granat (2008) examined the validity of piezoelectric pedometers in the older population (71.9 ± 5.7 years) and showed an underestimation of steps at the slowest walking speed (2.41 km/h).

Pedometers are typically worn at the waist. However, previous research suggested that the ankle might be a more suitable location for step counting at slow walking speeds (Bassett & Dinesh, 2010; Feito, Bassett, & Thompson, 2012; Karabulut, Crouter, & Bassett, 2005; Shepherd et al., 1999; Tangney et al., 2011). Compared with waist-worn devices, ankle-worn devices are not susceptible to errors due to motion of soft tissue and are more sensitive to movement. To our knowledge, no previous study in either young or old adults has yet tested the validity of a low-cost piezoelectric pedometer worn at the ankle.

In addition to pedometers, more expensive multisensors can be used for step counting. The newest Sensewear Mini Armband (SW, BodyMedia, Pittsburgh, PA, USA) includes several physiological sensors along with a triaxial accelerometer, given the capacity to motion measurement in three dimensions. To our knowledge, the SW has not yet been validated for step counting in either young or old adults.

Most research on step count accuracy focused on the young-old (65–74 yr) or community-dwelling older population. An important gap in the literature is the limited information on the validity of pedometers in the old and old-old, especially in institutionalized older adults. Moreover, limited data exists under free-living conditions (Cavalheri et al., 2011; Langer et al., 2009). Most studies have established the validity of pedometers and accelerometers under controlled conditions (e.g., treadmills) (Cyarto, Myers, & Tudor-Locke, 2004; Furlanetto et al., 2010; Grant et al., 2008; Marsh et al., 2007). However, in daily life, motion sensors are subject to other sources of error. For example, the walking speed obtained in a lab may be higher than ambulatory walking speed**.**

Because of the increasing need to measure PA, and in particular step counts among the old and the old-old, the purpose of the present study was twofold. The first aim was to assess the utility of an inexpensive piezoelectric pedometer worn at the hip and at the ankle during daily activities among nursing home residents. Simultaneously, the multisensor Sensewear Mini will be evaluated for step counting. We hypothesized that the ankle-worn pedometer is most accurate for quantifying steps (hypothesis 1). The second aim of this study was to investigate whether walking speed or the use of walking aids impair the performance of the hip- and ankle-worn pedometer and arm-mounted multisensor. Based on past work in the old and old-old, it was hypothesized that walking speed would be the significant predictor of step count accuracy (hypothesis 2).

METHODS

Participants

Eighty-two residents, 67 females and 15 males volunteered to participate in this study. Participants were recruited in three nursing homes in Flanders, Belgium. The participants were screened for following inclusion criteria by a general practitioner: 70 years or older, able to walk alone with or without walking aid, no vestibular or thrombotic disorder, no recent cardiovascular event or fracture, no severe dementia (MMSE $\geq$ 18) and no need for oxygen supplementation during daily activities. General practitioner's permission was obtained, and participants gave written informed consent. All procedures were approved by the human Ethics Committee of the KU Leuven.

Procedure

Study design

All measurements were conducted by one investigator at the nursing home where the participants resided. Participants attended three testing days.

On the first day (1) height and weight were assessed with a stadiometer and an electronic scale. (2) Physical dependency was measured by the Katz-index. Participants are ranked into five categories according to their ability to perform activities of daily living (i.e. O, A, B, C and Cd; O = complete independence, Cd = complete dependence (Katz et al., 1963). (3) Functional exercise capacity was measured using the six-minute walk test (American Thoracic Society, 2002). During this test, (4) step length was also determined. While participants were walking, the investigator marked a starting point behind the heel of the left foot and counted 10 steps. At the 10^{th} step, he marked a second point, again behind the heel of the left foot. Distance between the two points was measured and divided by 10. The average of 2 measurements was included in the analyses. (5) The Mini Mental State Examination (MMSE), a 30-point questionnaire, was used to screen for cognitive functioning (Folstein, Folstein, & McHugh, 1975).

On the second day, all participants were submitted to two additional measurements: (6) Functional performance was measured using the modified Physical Performance Test (mPPT). It is a performance-based measure of functionality related to daily activities. If the individual scores lower than17 on a maximum score of 36, the individual is considered as no longer independent (Brown et al., 2000). (7) Normal walking speed (expressed in km/h) was also determined, by having participants walk 7.5 m in a straight line as in their daily walking. Distance was divided by time to compute walking speed**.**

On the third day the validation test was carried out. For validation, participants wore the piezoelectric pedometers New Lifestyles 2000 (NL) (New-Lifestyles Inc., Lee's Summit, MO, USA) and multisensor Sensewear Mini (SW) (BodyMedia Inc., Pittsburgh, PA, USA) simultaneously. Consistent with previous studies, actual steps were observed and recorded at the completion of each task by one investigator using a hand-tally counter as criterion method (Tudor-Locke, 2002). The investigator counted steps for all participants, but did not assist the residents and was therefore not distracted by the residents when counting steps. In the current study, a step was defined if the foot was repositioned to change the base of support. Horizontal translation of the foot was required to in order to count a step.

Validation protocol

Participants underwent a 30-minute standardized protocol in which they performed three different tasks during a given time. The tasks, each lasting 4 minutes and separated by 4 minutes rest, were representative of some everyday life activities and based on the Glittre ADL-test (Skumlien et al., 2006). More specifically, participants had to (1) walk between two cones positioned 5 m apart, (2) to rise from a chair and sit in another chair positioned 5 m apart, and (3) to move objects. The objects, used in daily life and weighting less than 500 g had to be moved from one table to another table positioned 5 m apart. Participants walked at self-selected speed and usual walking aids were allowed. They were assisted by a second investigator, ensuring the safety of the individual in case of loss of balance. The investigator walked behind the participant to avoid influencing participants' walking speed.

<u>Materials</u>

The piezoelectric pedometer NL uses a piezoelectric accelerometer mechanism. Due to acceleration, a piezoelectric crystal compresses and generates a voltage. Voltage oscillations are used to record steps. Participants wore the pedometer secured to a waist-worn belt, close to the midline of the thigh as per the manufacturer's instructions. In the present study, participants were also equipped with a pedometer at the ankle, just above the lateral malleolus. Devices were worn on both the right and left sides of the body.

The multisensor SW was worn over the triceps muscle of the left arm, according to the manufacturer's instructions. The device includes a triaxial accelerometer, given the capacity for 3-dimensional spatial movement measurement. The SW counts steps on a minute-by-minute basis.

<u>Statistical analyses</u>

Data were analyzed using SPSS software version 16.0 (Chicago, IL). For all analyses, the significance level was set at $p < .05$. Pearson's product moment and Intra-class correlations between step counts from each device and manual step counts were calculated. A correlation >.70 was defined as representing evidence of validity (Touliatos, Perlmutter, & Straus, 2001). To facilitate comparison, percent error score was calculated as [(actual steps – device steps)/actual steps x 100]. In addition, agreement for step counts was studied by the Bland and Altman method, where differences are plotted against average scores. Regression analysis was performed to determine whether variables (e.g., walking speed and walking aid) contribute to percent error scores. Finally, to define a relevant threshold value for walking speed, Receiver Operator Characteristic (ROC) curves were obtained.

RESULTS

Sample characteristics

A total of 82 men and women initially consented, and were considered eligible by the nursing home staff. Fourteen participants dropped out after base measurements (day 1 and 2) for a variety of reasons: death (n = 2), loss of interest (n = 5), health conditions (n = 6) or anxiety (n = 1). As a result, 68 participants were included in the final statistical analyses. Drop-out analyses revealed no significant differences between participants and drop-outs for the variables listed in Table 1. Descriptive statistics are summarized in Table 1.

The final study sample consisted of 14 male and 54 female, aged between 71.2 and 97.8 years old. Participants had low scores on physical performance tests and had an average walking speed of 2.01 ± 0.68 km/h (range = 0.69–3.54 km/h). Forty-seven percent scored below 24 on the MMSE, suggesting the presence of cognitive impairment (Folstein, Folstein, & McHugh, 1975).

Data completeness

Five participants did not have complete data. Three residents had missing *total* step count data for all devices, because they could not complete the whole protocol due to tiredness. In addition, two residents had incomplete *total hip* pedometer data, because of a practical problem with the waist-worn belt securing the pedometers during one or two tasks.

Validity evidence

As shown in Table 2, the number of steps registered by the SW and NL were significantly lower than actual steps, for each task and for the sum of the three tasks. SW, NL hip and NL ankle significantly differed from each other. However, no significant differences emerged between pedometers worn on the right and left sides of the body. Consequently, for the purpose of this study, the two sides were averaged for further analyses.

Table 2 shows that there were substantial differences between devices in capturing steps in the old and old-old. This was also reflected in the Pearson's correlation and Intraclass correlation coefficients (ICC) between manual step counts and device-determined step counts (Table 3). The agreement between the measures was not acceptable, with the exception of the ankle-worn pedometer. Therefore, only the ankle-worn pedometer was used in further analyses.

Table 1. Sample characteristics (N = 68).

Variable	**Mean ± SD**
Female (%)	79.4 %
Age (yr)	85.8 ± 5.6
Institutionalized period (yr)	3.1 ± 3.2
BMI (kg/m²)	28.8 ± 5.4
MMSE scores 0–30	22.3 ± 5.7
Katz index (%)	
O	14.7 %
A	29.4 %
B	33.8 %
C	2.9 %
Cd	19.1 %
mPPT scores 0–36	16.8 ± 7.4
6MWD (m)	167.5 ± 74.7
Walking speed (km/h)	2.0 ± 0.7
Step length (cm)	36.1 ± 10.0
Walking aid (%)	
None	30.9 %
Rollator/walker	52.9 %
Cane/crutch	11.8 %
Physical assistance	4.4 %

Note. Presented as mean ± SD or as otherwise indicated. Abbreviations: BMI = Body Mass Index; MMSE = Mini Mental State Examination; mPPT = modified Physical Performance test; 6MWD = six-minute walk distance.

Table 2. Comparison of step counts given by observation (actual steps) and recorded by SW and NL (device steps) for each of the three tasks and during the entire protocol (sum of all tasks). Percent error = [(actual steps – device steps)/actual steps] x100.

Tasks	**Device**	**Steps ± SD**	**Percent error ± SD**
Walking	Actual steps	296.0 ± 73.2	
	SW	27.5 ± 51.6*	91.9 ± 14.9
	NL left hip	83.6 ± 97.0*§	74.5 ± 27.4
	NL right hip	79.7 ± 92.8*	75.6 ± 26.3
	NL left ankle	242.5 ± 108.9*¥	21.5 ± 25.8
	NL right ankle	243.8 ± 116.4*	21.1 ± 30.5
Rising/sitting in chairs	Actual steps	161.6 ± 58.0	
	SW	25.6 ± 53.4*	87.5 ± 21.8
	NL left hip	53.0 ± 65.0*§	71.2 ± 28.2
	NL right hip	51.4 ± 63.1*	72.4 ± 27.3
	NL left ankle	134.9 ± 73.3*¥	20.8 ± 26.5
	NL right ankle	136.7 ± 74.4*	19.5 ± 30.2
Moving objects	Actual steps	230.8 ± 66.8	
	SW	30.8 ± 57.3*	89.5 ± 18.2
	NL left hip	70.2 ± 77.6*§	73.2 ± 26.5
	NL right hip	70.5 ± 75.8*	73.5 ± 25.8
	NL left ankle	182.2 ± 79.2*¥	24.3 ± 21.0
	NL right ankle	188.7 ± 90.0*	21.7 ± 27.6
Total	Actual steps	693.3 ± 177.7	
	SW	85.9 ± 150.5*	89.6 ± 17.2
	NL left hip	213.4 ± 234.0*§	72.5 ± 27.2
	NL right hip	206.8 ± 223.9*	73.5 ± 25.8
	NL left ankle	568.8 ± 244.6*¥	21.4 ± 22.8
	NL right ankle	577.1 ± 264.8*	20.2 ± 28.4

Note. Abbreviations: SW = multisensor Sensewear Mini; NL = pedometer New Lifestyles 2000. Bonferroni adjustment for pairwise comparisons.

* $p < .05$ vs. actual steps

§ $p > .05$ vs. NL right hip

¥ $p > .05$ vs. NL right ankle

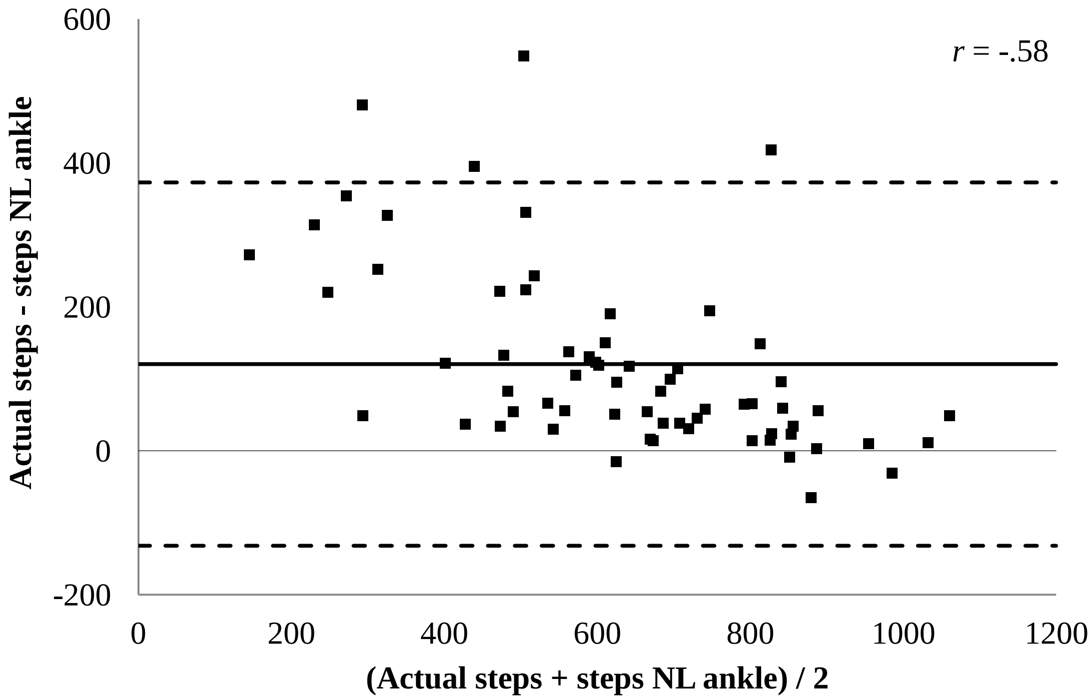
Table 3. Correlation coefficients and intraclass correlation coefficients between actual steps and steps recorded by SW, NL hip and NL ankle during the entire protocol.

Device	***r***	**ICC**	**[95% CI]**
SW	.50*	.06	[-0.03, 0.25]
NL hip	.60*	.15	[-0.06, 0.45]
NL ankle	.87*	.72	[0.19, 0.88]

* $p < .05$

The accuracy of the ankle-worn pedometer was poor. The Bland and Altman plot for the ankle-worn pedometer (Figure 1) depicts an average underestimation of 120.4 steps of an average of 693.3 steps for the entire protocol. The wide limits of agreement indicate a great variation in step count accuracy. It should be noted that the agreement increased as step counts increased, $r = -.58$; $p < .05$.

Figure 1. Bland-Altman plot depicts the agreement between step counts registered by the ankle-worn pedometer versus actual step counts during the entire protocol. The line in bold corresponds to the mean difference, whereas the dotted lines correspond to the upper and lower limits of agreement.



Determinants of pedometer accuracy

The percent error of the ankle-worn pedometer was negatively correlated ($p < .05$) with the following variables: six-minute walk distance ($r = –.57$); step length ($r = –.56$) and walking speed ($r = –.65$). The use of a walking aid ($r = .42$) increased the percent error of the ankle-worn pedometer. No systematic effect of BMI was found.

A stepwise regression analysis was performed with percent error as criterion variable and the variables listed in Table 4 as predictors. Walking speed emerged as only significant predictor and explained 41.6% of the variance in percent error of the ankle-worn pedometer, $\beta = –.65$, $t = –6.82$, $p < .05$. In our sample, pedometer accuracy improved as walking speed increased. Percent error is plotted as a function of walking speed for the three devices in Figure 2.

Table 4. Stepwise multiple linear regression model of variables associated with percent error of the ankle-worn NL during the entire protocol.

Predictor variables	**β**	***t***	***F*-value**	***R*²**	**Adj *R*²**
Walking speed	-.65	-6.82*	46.52	.43	.42
Excluded variables					
Step length	-.23	-1.83			
Walking aid	.12	1.03			
6MWD	-.21	-1.56			

Note. Abbreviation: 6MWD = six-minute walk distance.
* $p < .05$

Impact of walking speed on accuracy

Because walking speed significantly predicted percent error of the ankle-worn NL (Figure 2), the ROC method was used to determine a cutoff value of walking speed for accurate step counting. Walking speeds of nursing home residents above this threshold would result in an accurate quantification of steps. Figure 3 represents the ROC curve, plotting the false-positive rate versus the true-positive rate for each possible cutoff value. The cutoff value for accurate step counts with the ankle-worn pedometer yielded the best compromise between sensitivity (0.84) and 1 - specificity (0.13) and was set at 2.35 km/h, providing percent error scores within ± 5%.

Figure 2. Scatter plots of walking speed (km/h) and percent error [(actual steps – device steps)/actual steps x100] of the three devices: SW (x), NL hip (□), and NL ankle (•).

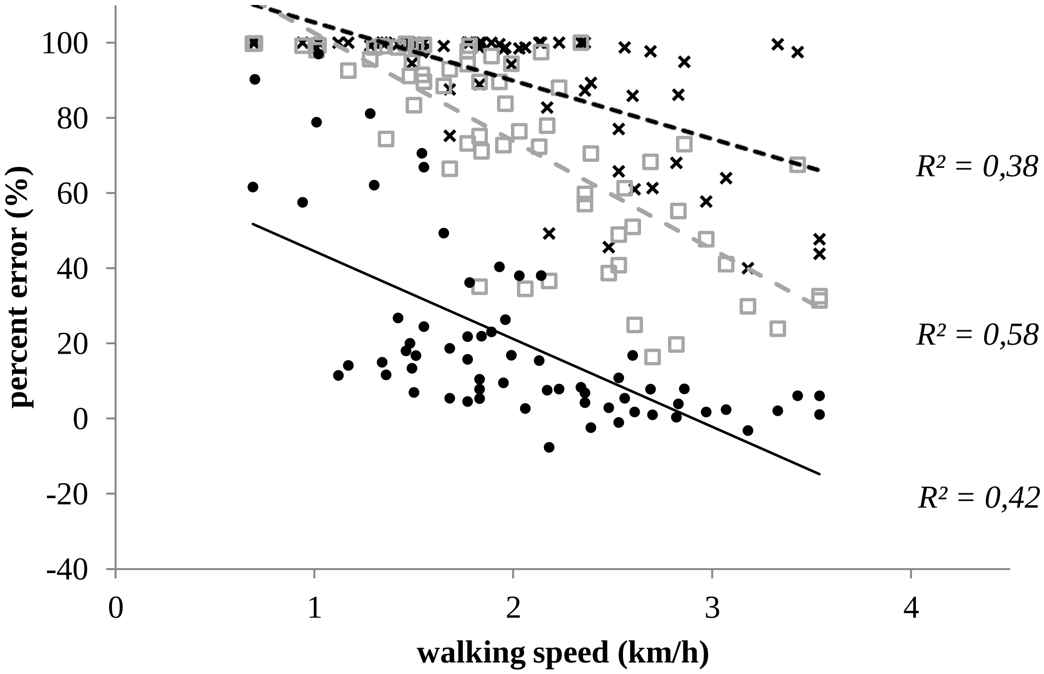
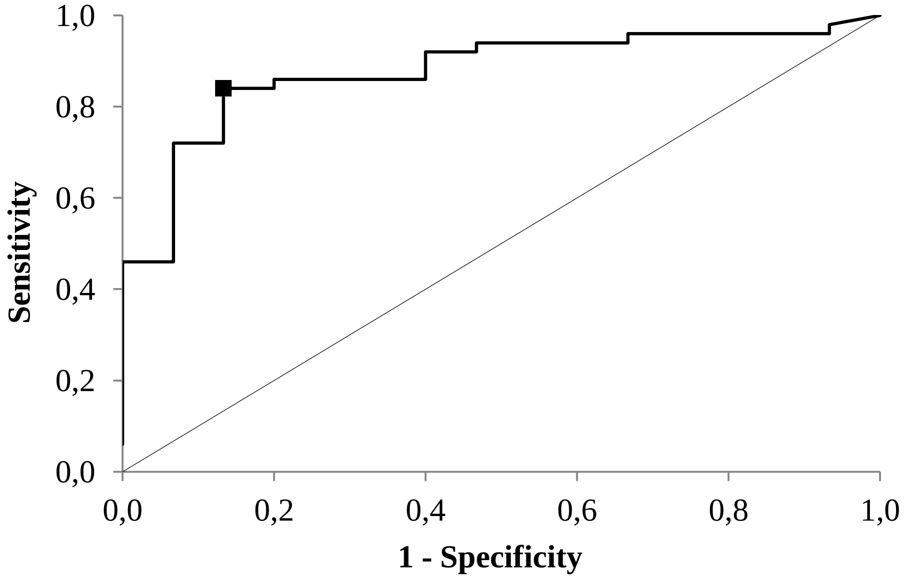


Figure 3. ROC curve for the identification of the threshold value for walking speed. The X-axis represents false-positive rates, the Y-axis true-positive rates. (■) yields the best compromise between sensitivity and specificity. Area under the curve indicates a discriminative value of .88 [95% CI 0.79 – 0.97].



DISCUSSION

Main findings

In this study, we investigated the step count accuracy of a hip- and ankle-worn piezoelectric pedometer and an arm-mounted multisensor during daily life activities in institutionalized older adults. The results showed that, in the three wearing conditions (arm, hip and ankle), steps were significantly underestimated (Table 2). However, there were substantial differences in performance between the three conditions. More specifically, the arm-mounted SW underestimated the number of steps by approximately 90%, while the hip- and ankle-worn pedometer underestimated the number of steps by approximately 70% and 20%, respectively.

With respect to the SW, previous research had already shown that the Sensewear Pro Armband poorly estimated the number of steps (Cavalheri et al., 2011; Furlanetto et al., 2010; Manns & Haennel, 2012). A possible explanation for the high percent error in step counts is that the device is worn around the upper arm. This is not an ideal wearing position for step detection, as older adults have a diminished arm swing (Touhy, 2012). However, to our knowledge, the present study was the first to test step count accuracy of the multisensor Sensewear Mini, including a triaxial instead of a biaxial accelerometer. The measurement of accelerations in three dimensions (instead of two dimensions) could improve step count accuracy. Nevertheless, our study revealed a higher percent error than previous studies using the Sensewear Pro Armband. A first possible explanation is that the walking speed in our study was lower than the walking speed reported in previous studies (2.0 ± 0.68 km/h vs. 2.90 ± 0.61 km/h) (Cavalheri et al., 2011). A second possible explanation is that 70% of our participants used a walking aid, which not only reduced walking speed, but also diminished their arm swing (Manns & Haennel, 2012).

With respect to the piezoelectric pedometer, the measurement accuracy was considerably lower when it was worn at the hip than when it was worn at the ankle. A possible explanation for this discrepancy is that a vertical wearing position, which is recommended by the manufacturer, is more easily maintained at the ankle. Differences in body shape and in how the device is attached to clothing can influence the positioning of the pedometer at the hip (i.e., the tilt angle) and thus reduce accuracy. Moreover, movements at the hip are less obvious in the old and old-old as there is a decrease in step length and step height (lifting of the foot when taking a step) (Touhy, 2012). Less than 30% of actual steps were recorded by the hip-worn piezoelectric pedometer, indicating an error of 70%. This finding concurs with previous validation studies in younger adults, which revealed gross underestimation at slow treadmill speeds. For example, Foster et al. (2005) and Melanson et al. (2004) counted 61 ± 3.3% and 56.4 ± 33.8% of actual steps at 1.61 km/h respectively, while Karabulut et al. (2005) counted less than 20% of actual steps.

In line with hypothesis 1, the ankle-worn pedometer was clearly the most accurate measurement tool when quantifying steps. This finding is consistent with that of Tangney et al. (2011), who found that a spring-levered pedometer at the ankle was the most cost-effective and accurate device for use at the slowest speed. To our knowledge, no study has yet tested the validity of an ankle-worn piezoelectric pedometer in the old and old-old. The ankle-worn pedometer had a strong correlation with manual step counts (r = .87, p < .05). Nevertheless, the percent error scores remained high (20.8 ± 24.6%).We had expected lower percent error scores as piezoelectric pedometers are considered more sensitive than spring-levered pedometers (Crouter, Schneider, & Bassett, 2005; Melanson et al., 2004; Schneider et al., 2003). Moreover, the (rather expensive) ankle-worn Stepwatch activity monitor (OrthoCare Innovations, Seattle, WA, USA) has been shown to be the most accurate device for step counting, also in the old and old-old (Bassett & Dinesh, 2010). However, our study still showed a significant underestimation of steps at the ankle in institutionalized older adults. A possible explanation is the slow walking speed measured in our study sample.

Walking Speed and Use of Walking Aids. In line with hypothesis 2, the current study revealed a clear impact of walking speed in the old and old-old. Measurement accuracy was reduced at slow walking speeds. More specifically, walking speed accounted for 42% of the variance in the percent error of the ankle-worn pedometer. A possible explanation is the shuffling gait pattern and gait impairments, which are often observed in slow walking older adults. This finding is generally consistent with other studies in young and old adults using piezoelectric pedometers. Marsh et al. (2007) found a significant correlation (ρ = –0.62, p < .001) between gait speed and the difference scores of a piezoelectric pedometer. In a study by Tyo et al. (2011), 43.3% of the variance in pedometer error was explained solely by stepping frequency, ß = –0.66; p < .001. On the other hand, it should be noted that this is the first study to test the step count accuracy of a piezoelectric pedometer worn at the ankle.

In addition, we identified a threshold value of walking speed for accurate step counting (percent error within 5%) in the old and old-old. More specifically, the ankle-worn pedometer proved to be acceptably accurate for quantifying steps at walking speeds of 2.35 km/h or above. Nevertheless, the number of steps remained underestimated, with a mean percent error of 3.9 ± 4.6% (p < .05). This finding is relevant for future studies concerning the old and old-old. Usual walking speed of each participant should be measured with a simple test and compared with the threshold value of 2.35 km/h. The ankle-worn piezoelectric pedometer is applicable for those participants whose walking speed exceeds the threshold value (i.e., 30% of our study sample).

In the present study, 70% of the participants required a cane or walker during the validation test. The use of walking aids may cause alterations in walking pattern. A significant correlation emerged between the use of walking aids and the percent error scores of the ankle-worn pedometer, r = .42; p < .05. However, stepwise regression analysis (Table 4) excluded the use of walking aids as a significant predictor, as it was negatively related to walking speed**.** Participants using a walking aid walked 1.78 ±

0.55 km/h while participants who did not require a walking aid walked 2.53 ± 0.66 km/h ($p < .05$). These findings are in agreement with those of (Webber et al., 2013), who reported slower walking speeds in individuals who used walking aids (2.99 ± 0.72 km/h versus 4.36 ± 0.72 km/h for non-walking aids users, $p < .001$).

Study strengths

A first strength of our study is that the sample was larger (n = 65) and considerably older (85.8 ± 5.6 years) than previous validation studies in older adults. Bergman et al. (2008), Grant et al. (2008), and Marsh et al. (2007) tested 21 participants (78.6 ± 13.1 years), 20 participants (71.9 ± 5.7 years), and 29 participants (75.8 ± 4.2 years), respectively.

A second strength is that two objective step counters were validated against the gold standard of manual step counts.

A third strength of this study is that participants performed activities in a daily setting, namely their nursing home. No treadmill or track was needed and distances could be standardized. Information obtained on a treadmill is difficult to generalize to daily life because of kinematic differences between treadmill and over ground walking (e.g., slower stride rates). Moreover, familiarization to a treadmill is difficult for older adults (Foster et al., 2005; Marsh et al., 2007; Wass, Taylor, & Matsas, 2005).

Study weaknesses

A first limitation of this study is that activities such as stair climbing, stationary bicycling and fidgeting movements (e.g., leg swinging and heel tapping) were not taken into account. However, these movements potentially result in the detection of erroneous steps. Karabulut et al. (2005) showed that the ankle-worn activity monitor Stepwatch was responsive to heel tapping, leg swinging and cycling; whether the waist-mounted pedometers recorded virtually no steps during these movements. On the other hand, they suggested that these movements would not make a meaningful contribution over a 24h period.

A second limitation is that we did not obtain a gait score (indicating possible gait problems). Cyarto et al. (2004) found that gait disorders hamper the utility of pedometers in nursing home residents.

CONCLUSION

In conclusion, the present findings indicate that the multisensor SW and the hip-worn piezoelectric pedometer are insufficiently accurate for quantifying steps during daily life activities in institutionalized older adults. By contrast, an ankle-worn pedometer can be useful, but only in the old and old-old walking faster than 2.35 km/h. Pedometers have a great ease-of-use and are well suited as inexpensive motivation tools because they provide immediate feedback. However, further research is needed to develop accurate measurement tools for quantifying steps in (institutionalized) older adults with slow walking gaits (< 2.35 km/h). Researchers and practitioners should consider this information when selecting a device for use in the old and old-old.

ACKNOWLEDGEMENTS

This study was conducted under the authority of the Policy Research Centre on Sports, supported by the Flemish Government.

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Energy expenditure in institutionalized older adults: Validation of Sensewear Mini

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Published in *Medicine and Science in Sports and Exercise*, 2015. 47(6),1265-1271.
doi: 10.1249/MSS.0000000000000529

ABSTRACT

Purpose: Objective methods to quantify physical activity (PA) and predict energy expenditure (EE) are needed in the old and old-old. The aim of the present study was to evaluate the validity of EE estimates by the Sensewear Mini (SWMini) compared with indirect calorimetry during daily life activities in institutionalized older adults.

Methods: Sixty nursing home residents (mean age = 85.5 ± 5.5 yr) wore the SWMini during rest (sitting quietly) and three activity tasks (walking, sitting/rising/walking and moving objects). SWMini data were processed using Software 7.0. The criterion EE ($kcal \cdot min^{-1}$) was estimated by a portable gas analyzer, Oxycon Mobile (OM).

Results: The analyses revealed high correlations ($r_{sitting} = .68$; $r_{activity\ tasks} = .88$) between EE estimated by OM and SWMini. EE increased between sitting periods and activity tasks for EE estimated by OM (mean difference = 61.5 ± 8.9%), as well as for EE estimated by SWMini (mean difference = 58.2 ± 7.4%) ($p < .001$). However, SWMini significantly underestimated EE, with an overall absolute percent error of 14.1 ± 7.9%. The largest absolute percent differences were observed during sitting periods compared with activity tasks ($p < .05$). Older age significantly reduced accuracy, explaining 12% of the variance in total percent error ($\beta = .42$; $t = 2.84$; $p < .05$).

Conclusion: The high percent error scores indicate that the SWMini is of limited value for quantifying EE in the old and old-old. The accuracy could be improved by developing accurate age- and activity-specific algorithms. On the other hand, the SWMini can be used as a suitable device for researchers interested in specific levels and patterns of PA and sedentary behavior.

Keywords: activity monitor; indirect calorimetry; validity; daily life activities; nursing homes

INTRODUCTION

The world's population is aging rapidly. The fastest growing segments are the old (75-84 years) and old-old, i.e., those being 85 years and older (Christensen et al., 2009). Muscle weakness and reduced physical fitness are most prevalent in the aging population and contribute to a loss of independence (Spirduso, Francis, & MacRae, 2005). Regular participation in moderate to vigorous physical activity (PA) is associated with reduced risk for disability and chronic conditions (Manini et al., 2006). The need for valid tools to measure PA has been identified as an important health research objective (Troiano, 2005).

Energy expenditure (EE) is a common outcome when assessing PA in daily life (Caspersen, Powell, & Christenson, 1985). Currently, indirect calorimetry (IC) (e.g., doubly labeled water [DLW]) is considered as the criterion variable (i.e., gold standard) for assessing EE (caloric consumption). However, these techniques are relatively expensive and/or require laboratory settings making them unfeasible for large scale studies. EE can also be estimated by activity monitors that use specific algorithms. These tools nowadays typically contain accelerometers in one or more directions and the information is sometimes complemented by other bodily information (heat rate, temperature etc.) (Ainslie, Reilly, & Westerterp, 2003). These devices are able to capture unstructured activities of light intensity (i.e., activities incorporated in daily life) that are often poorly reported on subjective questionnaires (Ainslie, Reilly, & Westerterp, 2003).

The use of multisensors, such as the Sensewear Armband (BodyMedia Inc., Pittsburgh, PA, USA) has gained widespread recognition. These devices combine accelerometry with non-invasive physiological sensors that measure conductivity, skin temperature and heat dissipating from the body. Multisensors have been shown to provide more accurate estimates of EE than accelerometry alone (Van Remoortel et al., 2012). Recently, a smaller and thinner version of the Sensewear Pro (SWPro) has been developed, labeled as the Sensewear Mini (SWMini). This device uses a triaxial instead of a biaxial accelerometer. A review by Vanremoortel et al. showed that triaxial devices are more accurate than uniaxial devices (Van Remoortel et al., 2012). Moreover, the internal exercise-specific algorithms are improved (BodyMedia, 2013). Johanssen et al. (2010) compared the SWMini against DLW over 14 consecutive days in a sample of 30 adults (38.2 ± 10.6 yr). Good agreements were observed between the SWMini and DLW estimates of EE (ICC = .85) and absolute error rate was 8.3 ± 6.5% (p = 0.07). The SWMini was also validated against IC in COPD patients (68 ± 7 yr) (Van Remoortel et al., 2012), wheelchair users with paraplegia (Hiremath & Ding, 2011) and pregnant women (Smith et al., 2012). Overall, the SWMini was highly correlated with IC (0.76 < mean r > 0.87), despite the fact that EE was significantly overestimated during most activities. These studies provided evidence for the reliability of the SWMini, but not for the accuracy of EE.

Although the SWMini has proven to be valid in a variety of populations, the applicability in the old and old-old is not well documented. In this specific older population, movements tend to be slower and they often make use of walking aids (Clarke et al., 2009). Previous work has illustrated that using a walking aid can result in an increased error variability and reduced agreement of the SWPro (Hill et al., 2010). To our knowledge, no previous study has tested the validity of the SWMini in institutionalized older adults. Moreover, most of the validation studies have been conducted under controlled laboratory conditions, using a treadmill or ergometry (Dwyer et al., 2009; Machac et al., 2013; Smith et al., 2012). Information obtained on a treadmill is difficult to generalize to daily life because of kinematic differences between treadmill and over ground walking (e.g., slower stride rates). Moreover, treadmill familiarization is difficult for older adults (Wass, Taylor, & Matsas, 2005). Validation studies performed under free-living conditions, or at least including a simulation of daily activities in a lab setting, provide a better test of validity because the nature of activities is more complex. Furthermore, one of the most important limitations imposed by older age is the reduced ability to perform daily activities.

Consequently, the first purpose of the present study was to examine the validity of the SWMini among the old and old-old during rest (i.e., sitting quietly) and during the performance of daily life activities. EE estimated by SWMini was compared with EE estimated by IC using different algorithms. The second purpose was to examine which factors (i.e., age, BMI, walking speed, the use of walking aids) impair the performance of the SWMini. We hypothesized that walking speed and the use of walking aids, because they diminish arm movements, would have a negative impact on the accuracy of the SWMini during activity tasks.

METHODS

Participants

Participants were recruited between October 2011 and April 2012 in three nursing homes in Belgium. The participants were screened for the following inclusion criteria by a general practitioner: 1) 70 years or older, 2) no severe dementia (MMSE ≥ 18), 3) no cardiac pacemaker, 4) no cardiovascular complaints or fracture in the last 4 months prior to the study, 5) able to ambulate with or without a walking aid, and 6) no need for oxygen supplementation during daily activities. The study was approved by the human Ethics Committee of the KU Leuven. The permission of the general practitioner was obtained and all participants provided written informed consent.

Study design

Participants attended three test sessions separated by at least 48h. All measurements were conducted by one investigator in the nursing home where the participants resided. Walking aids were allowed if normally used.

During **visit 1** participants were submitted to an assessment of 1) body weight and 2) body height. Weight was measured to the nearest 0.1 kg on a digital scale (Seca model 813) with the subject in light-weight clothing without shoes. Height was measured to the nearest 0.1 cm using a stadiometer (Seca model 213) with the subject not wearing shoes. 3) Cognitive function was determined with the 30-point Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). 4) Physical dependency was assessed using the six-item dependency scale by Katz (Katz et al., 1963). This scale ranks participants into five categories according to their ability to perform activities of daily living (i.e. O, A, B, C and Cd; O = complete independence, Cd = complete dependence). 5) Functional exercise capacity was measured using the 6-minute walk test (6MWT) (ATS Committee on Proficiency

Standards for Clinical Pulmonary Function Laboratories, 2002). This submaximal test measures the distance covered (in meters) in 6 minutes using a 20-m corridor.

During **visit 2** all participants were submitted to two additional measurements. 6) Normal walking speed ($km{\cdot}h^{-1}$) was measured during a 7.5m walk. Distance was divided by time, calculated as the mean of two measurements. 7) Functional performance was scored using the modified Physical Performance Test battery (mPPT) by Brown and Sinacore (Brown et al., 2000). The standardized mPPT consists of 9 items that focus on the performance of functional activities.

During **visit 3** the validation test (see below) was performed. During the protocol, EE was recorded by a portable metabolic system, Oxycon Mobile (OM; CareFusion Respiratory Care, Yorba Linda, CA, USA) and a multisensor, Sensewear Mini (SWMini; Bodymedia Inc., Pittsburgh, PA, USA), simultaneously.

<u>Validation protocol</u>

Each participant performed a standardized protocol lasting 30 minutes, which included activities representative of daily life based on the Glittre Activities of Daily Life (ADL)-test (Skumlien et al., 2006). Each activity was sustained for 4 min and separated by 4 min rest, during which participants were required to be seated quietly. The first and last sitting period lasted for 5 min each. Activities included 1) walking on the level ground between two cones positioned 5m apart, 2) rising from a chair and sitting in another chair positioned 5m apart, and 3) moving objects. The objects, used in daily life and weighting less than 500g had to be moved from one table to another table positioned 5m apart. Participants walked at a self-selected speed, and were allowed to use their walking aid. They were assisted by one investigator, ensuring the safety of the individual in case of loss of balance. The investigator walked behind the participant to avoid influencing participants' walking speed. The investigator time-stamped the SWMini to mark the start and the end of each activity. Another investigator initiated the portable gas analyzer OM. The internal clock in the SWMini was synchronized with the clock in the OM.

<u>Instrumentation</u>

The wireless monitor SWMini was used for estimating EE, expressed in $kcal{\cdot}min^{-1}$. The device was worn over the triceps muscle on the left arm at least 15 minutes before starting the protocol to allow adaptation to body parameters. The SWMini includes a triaxial accelerometer along with physiological sensors; a heat flux sensor estimating heat loss from body, a galvanic skin response sensor estimating conductivity of the skin and a skin temperature sensor. The device estimates EE minute-by-minute through automatically applied algorithms developed by the manufacturer. The complex pattern recognition algorithms classify each minute in a specific activity class. Each activity class has a linear regression model using information regarding accelerometry, physiological sensors and participant's demographic characteristics (e.g. gender, age, height, weight, smoking habit and handedness). The raw data were downloaded to a personal computer and processed using the professional software (Innerview Research Software, version 7.0, BodyMedia Inc., Pittsburg, PA).

The OM is a portable metabolic system measuring EE via pulmonary gas exchange (Hannink et al., 2010). The OM was turned-on at least 30 min prior to testing and calibrated according to the instruction manual before each test. The system was secured to the upper-chest with a harness. A flow sensor unit was connected to a face mask fitted over the participants' mouth and nose (Hans Rudolf, Inc., Kansas City, MO, USA). This unit detects the air flow by the rotation of a low-resistance turbine. Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured breath-by-breath and averaged over 30-sec epochs. These values were converted into kilocalories, using the Weir formula [(3,9 x VO_2) + (1,1 x VCO_2)] and expressed in $kcal \cdot min^{-1}$ (WEIR, 1990). After each test, data were downloaded to a personal computer.

Data processing

Oxygen uptake best estimates EE during physiological steady state. Steady state conditions were obtained if VO_2 values (averaged over 30-s epochs) had coefficients of variation less than 10% computed over windows of at least 1 minute. Consequently, the first two minutes of every task (for the first task, the first three minutes) were excluded and considered as an equilibrium period. As a result, data averaged over the last four 30-sec measures of each task (and over the last three minutes for the last task) were used in statistical analyses (Reeves et al., 2004).

Statistical analysis

Data were analyzed using SPSS software version 16.0 (SPSS Inc, Chicago, IL). For all analyses, significance was set at $p < .05$ (*) and $p < .001$ (**). Descriptive variables are presented as mean scores (± SD). Normality in the distribution of data was checked by the Kolmogorov-Smirnov test. Comparisons between men and women were performed by an unpaired t-test. The average EE during each task, expressed in $kcal \cdot min^{-1}$ was plotted to examine the profile of SWMini and OM. To facilitate comparisons between the two measures, the percent error was calculated as [(EE OM – EE SWMini)/EE OM x100] and was used as an outcome measure. Paired t-tests were calculated to compare OM estimates and SWMini estimates of EE. Correlations were calculated by Pearson's product moment and intra-class correlations (two-mixed model for absolute agreement). The ICC was interpreted as follows: between .40 and .60 as moderate agreement, between .61 and .80 as substantial agreement, and above .80 as good agreement (Landis & Koch, 1977). In addition, agreement between measures was studied by Bland and Altman, plotting differences against average scores. The 95% predictions limits were calculated. A regression analysis was conducted, using data from participants having complete datasets, to determine which variables (e.g., age, sex, BMI, walking speed and walking aid) affected the accuracy of SWMini.

RESULTS

Sample characteristics

Eighty-seven residents that were considered eligible by the nursing home staff were approached. Seventy-four residents initially consented. A total of fourteen residents withdrew after visit 1 and 2. Those residents did not take part in the validation test during day 3 due to death (n = 2), worsened health conditions (n = 6), loss of interest (n = 5) or anxiety for the test (n = 1). As a result, 60 residents participated in at least one activity task or sitting period and were included in the final statistical analyses (Table 1). Participants ranged in age from 71.2 to 95.6 yr. A little more than half of the participants scored lower than 17 on the mPPT, indicating frailty and a loss of independency (Brown et al., 2000). Approximately 40% of participants were obese (BMI ≥ 30 $kg \cdot m^{-2}$).

Data completeness

Of the 60 participants enrolled in the study, complete datasets were available for 40 participants (66.7%). Fifty-three participants completed all sitting periods, while 42 participants completed all activity tasks (see Table 2). For twenty participants, complete dataset could not be collected because of various reasons: thirteen participants were not able to complete the 4 minutes of one or two activity tasks due to fatigue; three participants had to stop the protocol after walking due to tiredness; two participants had to detach the OM during the protocol due to problems in adaptation with the mouthpiece. A technical error in the OM resulted in lost data for one activity for two participants. The available data of participants having incomplete datasets were only used when appropriate, namely in the analyses concerning the specific tasks they had performed.

Table 1. Sample characteristics (N = 60).

Variable	**Mean**	**(SD)**
Female (%)	78.3	
Age (yr)	85.5	(5.5)
Institutionalized period (yr)	3.4	(3.3)
Weight (kg)	70.2	(12.6)
BMI ($kg \cdot m^{-2}$)	29.2	(5.0)
mPPT scores 0–36	17.2	(7.6)
6MWD (m)	170.5	(77.3)
Walking speed ($km \cdot h^{-1}$)	2.1	(0.7)
Walking aid (%)	66.7	

Note. Presented as mean (SD) or as otherwise indicated. Abbreviations: BMI = Body Mass Index; mPPT = modified Physical Performance test; 6MWD = six-minute walk distance.

Validity evidence

Table 2 contains the EE estimates from SWMini and the criterion EE estimates. Significant linear correlations between SWMini and OM were observed for the sum of all activity tasks and sitting periods, and for the sum of all tasks. Agreement between measurements was substantial to good, except during sitting periods. EE estimated by SWMini significantly differed from EE estimated by OM for all tasks, with an overall absolute percent error of 14.10 ± 7.94% [1.81% - 35.16%]. The largest absolute percent differences were observed during sitting periods compared with activity tasks ($p < .05$). Higher absolute percent error scores were reported for women, although the difference was not significant (15.22 ± 8.46% in women compared with 11.13 ± 5.69% in men).

On average, SWMini reported lower levels of EE compared with OM. Bland and Altman plots emphasized this underestimation and revealed greater spread of EE for activity tasks (walking, sitting/rising/walking and moving objects). The plots in Figure 1 suggest that higher or lower EE was not associated with changes in agreement (R^2 slope during sitting periods = .03; R^2 slope during activity tasks = .06; $p > .05$). It should be noted that despite an average underestimation, the SWMini overestimated EE in 17% of the participants during sitting periods and in 33% of the participants during activity tasks.

Table 2. Comparison of EE estimated by OM and SWMini for the sum of all sitting periods and acitivity tasks, and during the entire protocol (sum of 15 minutes). Correlation (r) and Intraclass Correlation Coefficients (ICC) between EE OM and EE SWMini are reported.
Absolute percent error = |[(EE OM - EE SWMini)/EE OM]| x 100

Task	N	Mean energy cost		Absolute %error ± SD	r	ICC [95% CI]
		OM ± SD ($kcal \cdot min^{-1}$)	SW ± SD ($kcal \cdot min^{-1}$)			
Sitting periods	53	1.31 ± 0.25	1.07 ± 0.22**	19.06 ± 9.91	.68**	.45** [-.08, .74]
Activity tasks	42	3.17 ± 0.88	2.93 ± 0.99*	13.88 ± 9.81	.88**	.85** [.68, .92]
Sum of all tasks	40	2.07 ± 0.47	1.81 ± 0.51**	14.10 ± 7.94	.88**	.79** [.23, .92]

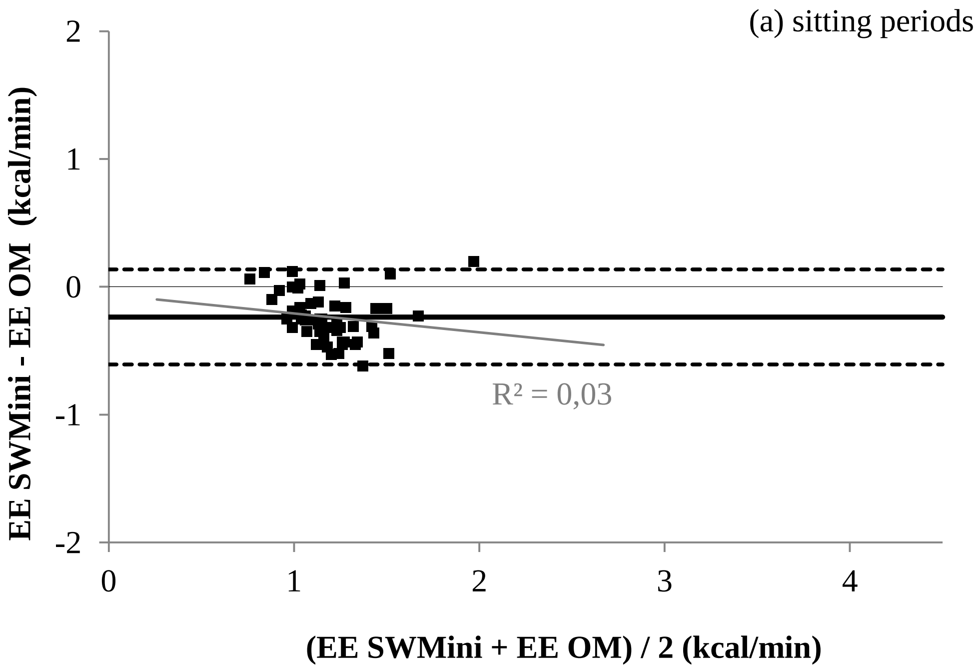
Predictors of accuracy

A regression analysis was performed, using data of all participants having complete datasets (n = 40), with total percent error as criterion variable. Total percent error of the SWMini was correlated with age (r = .42; p < .05). Older age significantly reduced accuracy and explained 12% of the variance in total percent error of the SWMini (β = .42; t = 2.84; p < .05). No significant correlations were observed between percent error and sex, BMI, walking speed or the use of walking aids.

Energy cost of daily life activities and sensitivity of the Sensewear Mini

A graphical overview of the average EE assessed by OM and SWMini for all participants is provided in Figure 2. There were clear differences in EE between sitting periods and activity tasks for EE estimated by OM (mean difference = 61.50 ± 8.90%), as well as for EE estimated by SWMini (mean difference = 58.24 ± 7.44%) (p < .001). There were no significant differences in EE between the activity tasks for both measurements (p > .05). During sitting periods, only the first sitting period showed lower levels of EE in comparison to the other sitting periods (p < .001).

Figure 1. Bland-Altman plots depict the agreement between EE estimated by SWMini versus EE registered by OM during sitting periods (a) and activity tasks (b). The line in bold corresponds to the mean difference between the respective methods, whereas the dotted lines correspond to the upper and lower limits of agreement.



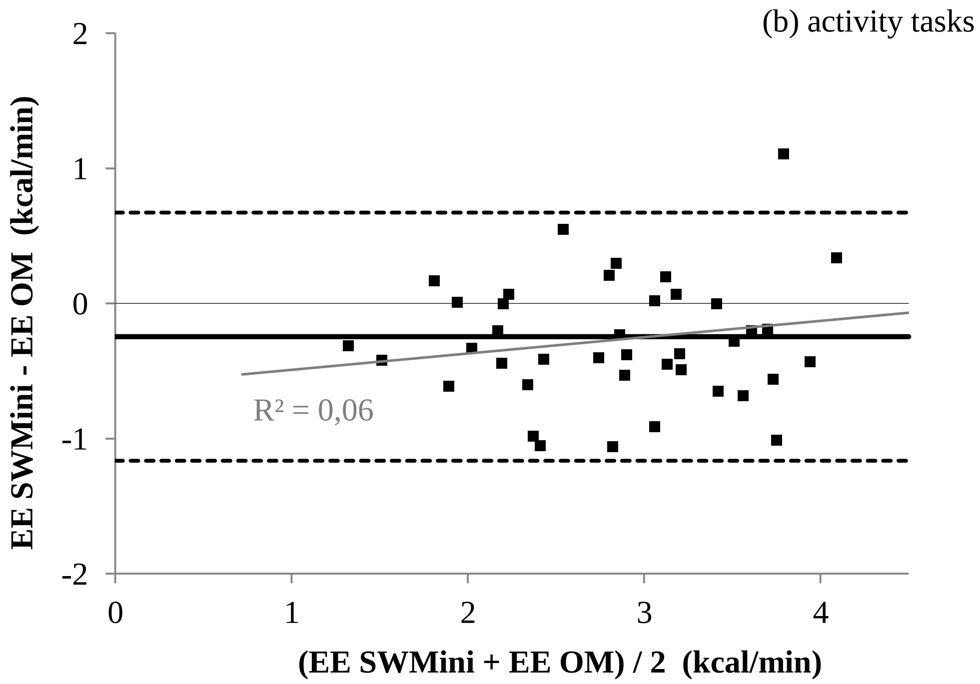
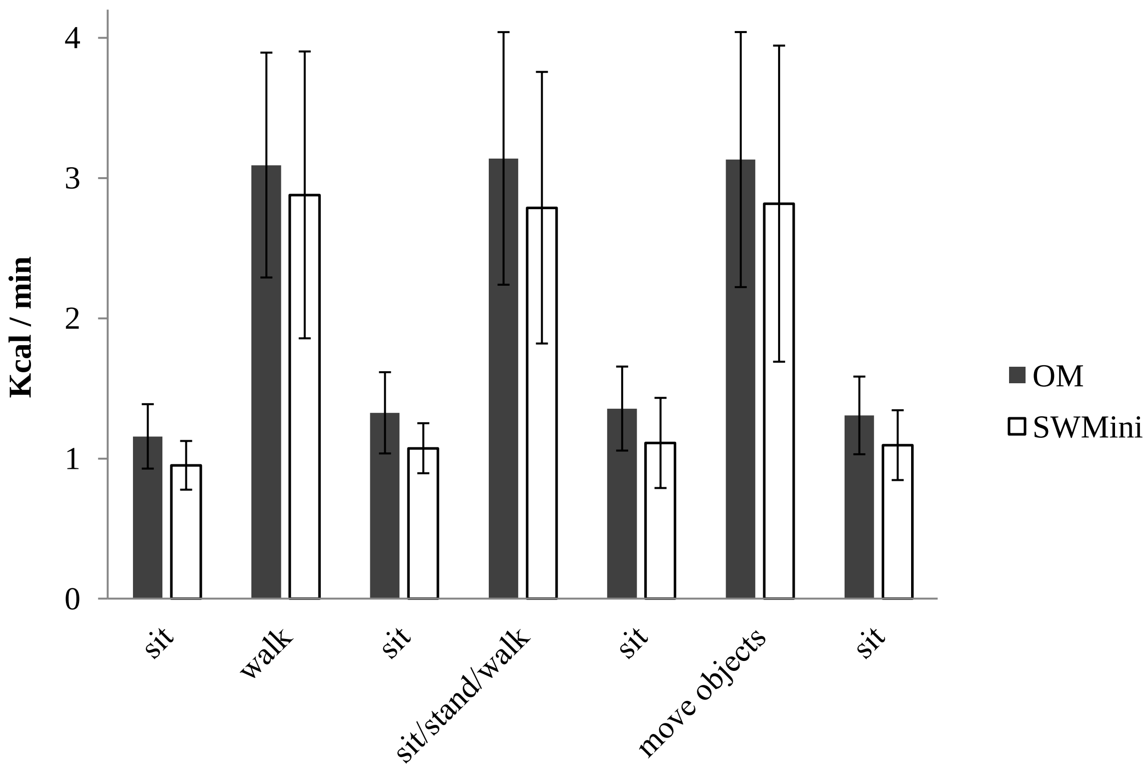


Figure 2. Comparison of mean (±SD) EE expressed in kcal/min for each task obtained by OM (■) and SW (□) (error bars are ±1SD).



Note. Abbreviations: OM = portable gas analyser Oxycon Mobile; SW = multisensor Sensewear Mini.

DISCUSSION

Main findings

To our knowledge, no previous study had tested the validity of SWMini during an activity-specific protocol in the old and old-old. Therefore, the main purpose of this study was to test the accuracy of the SWMini in estimating EE during daily life activities of this population. The SWMini demonstrated good agreement (ICC > .75). Notwithstanding, estimates from the SWMini were significantly lower than the criterion values, with a mean absolute percent error of 14 ± 8%. EE by SWMini was underestimated in 84% of the participants.

Mackey et al. (2011) validated the older model SWPro over an extended period of time in older adults (mean age = 82 yr) and showed acceptable levels of agreement. However, one should be careful in comparing their findings with the findings of the present study considering the differences in the criterion method that was used (DLW in Mackey et al. versus IC in our study). In contrast to our results, the majority of the validation studies using activity-specific protocols reported an overestimation of the SWPro and SWMini during walking and sitting (Cavalheri et al., 2011; Dwyer et al., 2009; Hermann et al., 2014; Machac et al., 2013; Smith et al., 2012). Some studies did not show a significant difference during walking activities between EE estimated by SWPro and EE estimated by IC (Hill et al., 2010; Patel et al., 2007).

A first possible explanation for the discrepancy between our findings and those reported in literature is the difference in technology and software. In the present study the newest SW model (SWMini) was used. Johannsen et al. (2010) showed better agreement for the SWMini compared with the older model SWPro in a sample of healthy adults. In the present study SWMini data were also processed with the software 7.0. Studies revealed significant differences between software versions. Smith et al. (2012) showed a significantly smaller error for the newer version 5.2 than the older version 2.2 algorithm in a sample of pregnant women, whereas Mackey et al. (2011) suggested that version 5.1 algorithms are more accurate than version 6.1 algorithms for older adults. It remains a problem to evaluate the validity of algorithms as they are proprietary to the manufacturer and there is no transparency in the changes that were made from one version to another.

A second explanation for the underestimation reported in the present study is related to the analysis of the data. In the present study, only steady state minutes were included in the analyses as oxygen uptake best estimates EE during physiological steady state (see methodology). By contrast, Cavalheri et al. (2011), Dwyer et al. (2009), and Smith et al. (2012) included data during non-steady state, which may have overestimated EE during some activities.

A third possible explanation concerns the characteristics of the participants: most validation studies have been performed in younger and/or community-dwelling older adults. When considering the predictors of accuracy in our study, age was positively correlated with total percent error ($r = .42$; $p < .05$). It is possible that the impact of aging on the accuracy of the SWMini occurs only at a later stage of life.

The underestimation reported in the present study suggests that older age might reduce the sensitivity of the triaxial accelerometer sensor (a) and physiological sensors (b). (a) The slow and shuffling walking patterns in the older population, which limit arm swing, make it difficult for the accelerometer to measure movement. Cyarto, Myers and Tudor-Locke (2004) showed a significant underestimation of step counts during walking in nursing home residents (mean percent error during slow walking = 73.9 ± 34.8%). In contrast to Hill et al. (2010) and Manns and Haennel (2012) the present study did not reveal an effect of the use of walking aids on the accuracy of EE during activity tasks.

(b) In addition, age-related changes in skin and body composition in the old and old-old could play an essential role as EE estimation by SWMini is also based on the input of three physiological sensors: a galvanic skin response sensor measuring the conductivity of the skin, a skin temperature sensor measuring the temperature of the skin and a heat flux sensor measuring the amount of heat dissipating from the body. Some of the changes in the skin include a breakdown of collagen and elastic fibers, and a decreased activity of the oil and sweat glands. These decreases cause the skin to become dry and less pliable, and make it more difficult for older adults to dissipate heat from the body and maintain thermoregulation (Spirduso, Francis, & MacRae, 2005). There is also a reduced blood supply to the skin, which contributes to a lower conduction (Spirduso, Francis, & MacRae, 2005).

The SWMini uses activity-specific algorithms to estimate EE. These algorithms probably do not take into account the abovementioned age-related changes in skin and body composition. Moreover, it should be noted that the percent error can be influenced by reduced movement efficiency in older adults. It is unlikely that the SWMini is able to capture all these factors as it is difficult to incorporate mechanical efficiency into the prediction model (Mian et al., 2006).

Sensitivity

The results of the present study revealed that the SWMini is insufficiently accurate for quantifying EE during daily life activities in the old and old-old when compared with a gold standard method. However, the SWMini can be used in studies describing sedentary behavior in the old- and old-old considering that this device detects interruptions in sedentary time. Figure 2 shows the ability of the SWMini to detect changes in EE associated with lower intensity (household) tasks (p < .001). This finding is consistent with findings from Hill et al. (2010), demonstrating that the SWPro was sensitive to detect differences (2.4 METs) in average EE between standing and slow walking. In the study by Hill et al. (2010), the device had adequate sensitivity to detect even a small increase (0.5 METs) in EE resulting from an increase in walking speed of 0.8 $km \cdot h^{-1}$. It should be noted that these authors reported higher walking speeds (3.1 ± 0.7 $km \cdot h^{-1}$ vs. 2.1 ± 0.7 $km \cdot h^{-1}$) and had a younger and fitter study population (67.4 ± 6.8 yr).

Independent of the level of moderate to vigorous PA, sedentary behavior has been demonstrated to be an important health risk factor (Tremblay et al., 2010). It is defined as the time spent in a sitting or lying posture where little energy is being expended (Sedentary Behaviour Research Network, 2012). Institutionalized older adults spend 70-80% of their waking hours being sedentary and perform only light intensity PA (MacRae et al., 1996). The SWMini can detect clear differences in EE between sitting periods and activity tasks. This finding is especially relevant as more interventions focus on the interruptions of sedentary time in older adults (Chastin et al., 2014).

Energy cost during daily life activities

For the purpose of this study, we did not use Metabolic Equivalents (MET) to quantify the energy cost. A caution supplied by the Ainsworth compendium is that MET-values are representative for adults without conditions altering their mechanical or metabolic efficiency (Ainsworth et al., 1993). Recent studies also questioned the accuracy of 3.5 $mLO_2 \cdot min^{-1} \cdot kg^{-1}$ to define 1 MET in older adults, as RMR decreases per decade (Luhrmann, Edelmann-Schafer, & Neuhauser-Berthold, 2010).

Institutionalized older adults spend on average 1.31 $kcal \cdot min^{-1}$ during sitting (Table 2). The energy-demand during activity tasks was on average 3.17 $kcal \cdot min^{-1}$ (estimated by OM). No significant differences in EE emerged between participants walking with and participants walking without a walking aid ($p > .05$). During sitting periods and activity tasks, men reported higher levels of EE than women (sitting: 1.53 ± 0.22 $kcal^{\cdot}min^{-1}$ vs. 1.23 ± 0.21 $kcal^{\cdot}min^{-1}$; activity tasks: 4.02±0.89 $kcal^{\cdot}min^{-1}$ vs. 2.87 ± 0.66 $kcal^{\cdot}min^{-1}$; $p < .001$). These values are comparable to those reported by Hermann et al. (2014), measuring EE in a sample of patients with osteoarthritis (63.3 ± 9.2 yr). They reported a mean EE of 1.1 $kcal^{\cdot}min^{-1}$, 3.0 $kcal^{\cdot}min^{-1}$ and 3.8 $kcal^{\cdot}min^{-1}$, during sitting, walking and sitting/rising/walking, respectively (vs. 1.28 $kcal^{\cdot}min^{-1}$, 3.08 $kcal^{\cdot}min^{-1}$ and 3.12 $kcal^{\cdot}min^{-1}$ in our study).

Study strengths and weaknesses

A first strength of the present study is that the sample was larger (n = 60) and considerably older (85.5 ± 5.5 yr) than previous validation studies in older adults using activity-specific protocols. Cavalheri et al. (2011), Vanremoortel et al. (2012), Hill et al. (2010), Hermann et al. (2014), and Patel et al. (2007) tested participants with a mean age of 69 ± 9 yr, 67.9 ± 7.4 yr, 67.4 ± 6.8 yr, 63.3 ± 9.2 yr and 61.5 ± 4.3 yr, respectively. Second, the selected activity tasks were typical activities in institutionalized older adults. The time frame and self-selected speeds made them relevant to daily life. These activities could be performed, because a portable gas analyzer was available. Many validation studies use fixed measurement devices. Therefore, the assessment of EE has been performed mainly in laboratory settings, often using treadmills. However, treadmill familiarization in older adults is difficult (Wass, Taylor, & Matsas, 2005). Moreover, treadmill walking cannot be easily generalized to over ground walking and is not a relevant condition for daily life activities.

A first limitation of this study is that activities such as stationary bicycling or upper limb activities were not evaluated. Previous studies reported that upper limb activities often result in larger percent error scores (Hermann et al., 2014). Although walking is the main activity of nursing home residents, additional studies including upper limb activities are needed before conclusions can be made about the overall agreement of the multisensor in the old and old-old. A second limitation is that test-retest reproducibility was not tested. It should be noted however that the SWPro showed good reproducibility in COPD patients (Hill et al., 2010; Patel et al., 2007).

CONCLUSION

This was the first study to evaluate the accuracy of the SWMini to assess (changes in) EE in institutionalized older adults. Despite the high correlation between EE estimated by OM and SWMini using different algorithms, there was an underestimation of EE during sitting periods and activities tasks. Further research is needed to develop accurate age- and activity-specific algorithms for quantifying EE in the old and old-old. Nevertheless, the findings of the present study suggest that activity monitors such as the SWMini can become a suitable device for researchers interested in the level and the patterns of PA and sedentary behavior in the old and old-old, which cannot be determined by other measures of EE such as DLW or pedometers.

ACKNOWLEDGEMENTS

This study was conducted under the authority of the Policy Research Centre on Sports, supported by the Flemish Government.

The authors would like to extend thanks to the Research Group for Cardiovascular and Respiratory Rehabilitation of the KU Leuven for providing the portable gas analyzer, Oxycon Mobile for this study.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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CHAPTER 2

Muscle strength and functionality in older adults

Paper 3 Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?

Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings?

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Published in *Archives of Gerontology and Geriatrics*, 2015. 60(2),252-258.

doi: 10.1016/j.archger.2014.11.010

ABSTRACT

Background: The first purpose was to examine whether knee extension strength is a better predictor of functional performance than handgrip strength among older adults (≥60y). The second purpose was to identify functionally relevant cut-off values for muscle strength.

Methods: 770 community-dwelling older adults, 104 older adults living in assisted living facilities and 73 nursing home residents were included. Static strength, expressed in kg/kg body weight (BW), was measured using two field tests: handgrip (GRIP/BW) and knee extension (KNEE/BW) test. Functional performance was assessed with 6-Minute Walk Distance (6MWD, N=947) and modified Physical Performance Test (mPPT, N=152).

Results: Both GRIP/BW and KNEE/BW were positively correlated with functional performance in all settings (p <0.05). In the community and nursing homes, both strength variables equally contributed to functional performance. In assisted living facilities, KNEE/BW (R^2_{6MWD} = 0.39 and R^2_{mPPT} = 0.35) was clearly a better predictor of functional performance than GRIP/BW (R^2_{6MWD} = 0.15 and R^2_{mPPT} = 0.12). GRIP/BW had no added value to KNEE/BW in order to explain the variance in functional performance. Functionally relevant cut-off values for static strength, for men and women respectively, were set at 0.40 and 0.31 for KNEE/BW and at 0.43 and 0.31 for GRIP/BW.

Conclusions: Handgrip and knee extension strength are both important predictors of functional performance in older adults. In assisted living facilities only, knee extension strength was clearly more predictive than handgrip strength. Both cut-off values appear to be highly sensitive to screen for functionally relevant muscle weakness in older adults.

Keywords: muscle strength; sarcopenia; reference values; frail older adults

Highlights:

- Handgrip and knee extension strength are important predictors of functionality.
- Knee extension determines function more than handgrip in assisted living facilities.
- Functionally relevant cut-off values for muscle strength were identified.

INTRODUCTION

Human aging is accompanied with declines in muscle mass and in muscle strength (Mitchell et al., 2012). The decline in muscle strength has been associated with reduced mobility and functional performance and increased risk of falling in older adults (≥60 years) (Lauretani et al., 2003; Macrae, Lacourse, & Moldavon, 1992; Marsh et al., 2011; Yang et al., 2013). Functional deterioration will eventually lead to a loss of independence, increased healthcare costs and institutionalization. Therefore, individuals at high risk for functional limitations need to be identified. Considering the association between muscle strength and functional performance, screening for functionally relevant muscle weakness is crucial in developing effective strategies to prevent or at least delay functional decline in the aging population.

For the quantification of muscle strength in older adults, dynamometric measures of handgrip and knee extension strength predominate (Bohannon & Magasi, 2014). Static handgrip strength measurements have been widely used in clinical practice because of their affordability, portability, simplicity and time-efficiency. Handgrip strength appears to be a good predictor of adverse outcomes such as hospitalization and mortality (Legrand et al., 2014). Even though handgrip strength has been proposed to reflect the overall strength status of an older individual (Visser et al., 2000), differences in activities requiring upper and lower body strength recommend caution when using a single action to describe overall muscle strength (Bohannon, 2008; Bohannon et al., 2012).

Aging is associated with a greater percent decline in lower than in upper limb muscle size and strength, which could have important implications for using grip strength as a physical marker of lower limb strength for those at risk for functional decline (Frontera et al., 2000; Newman et al., 2003; Samuel et al., 2012). The knee extensors in particular appear to be crucial in a variety of functional tasks, such as walking, chair rising and stair climbing (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002). In addition, knee extension strength is important to prevent falls and to maintain bone health of the proximal femur (Macrae, Lacourse, & Moldavon, 1992; Matsui et al., 2013).

The abovementioned arguments highlight the need for quantifying knee extension strength in addition to handgrip strength in older adults. To date, isokinetic dynamometry is considered the golden standard for measuring knee extension strength in scientific research (Drouin et al., 2004; Osternig, 1986). However, its practical applicability is limited because it is complex, time-consuming and costly. As a consequence, alternative isometric strength tests that strive for a quick and simple administration have been developed. One of these alternative tests is based on the knee extension strength test of the Physiological Profile Assessment (Lord, Menz, & Tiedemann, 2003). This static field test is a simple test on a portable chair using a digital dynamometer to measure maximal isometric knee extension strength.

An important question is whether this field test for static knee extension strength is a good measure to predict functional performance in older adults. If that is the case, the knee extension strength test can be used to screen for functionally relevant muscle weakness in older adults. When considering the older population (≥60 years), one should keep in mind that this population is highly heterogeneous, especially in level of functionality and dependence. To meet the diversity of needs among older adults, there are several housing facilities. The three primary housing facilities are the community setting, assisted living facilities and nursing homes. Given that older adults in these settings differ from each other in terms of needs related to functionality, it might be interesting to include separate analyses depending on the setting.

The first purpose of the current study was to examine whether static knee extension strength, measured with the field test, is a better predictor of functional performance in older adults (≥60 years) than handgrip strength. The three different living settings, as described above, will be taken into account. For developing effective strategies to counteract functional decline, it is also important to be able to identify persons with muscle weakness. For grip strength, normative data and cut-off values for muscle weakness are available in literature (Bohannon et al., 2006; Lauretani et al., 2003). However, the literature lacks data on functionally relevant cut-off values for knee extension strength. To be useful for large-scale screening purposes, these cut-off values should be based on simple field tests. Therefore, the second purpose of the current study was to identify functionally relevant cut-off values for static knee extension strength.

METHODS

Participants and study design

Data for this study were derived from five studies among older adults, conducted between 2009 and 2013 in Flanders, Belgium. These five studies included one validation study and four interventions studies in older adults, of which only the pretest data were included in these analyses (Martien et al., 2014; Pelssers et al., 2013; Van Hoecke et al., 2013; Van Roie et al., 2013). Participants gave written informed consent and all procedures were approved by the human Ethics Committee of KU Leuven.

These five studies, performed by investigators of the same research group, were selected because of their similarity with respect to the inclusion and exclusion criteria and in outcome measurements. Eligible participants had to be 60 years or older. For the maximal strength tests, exclusion criteria were unstable cardiovascular disease, acute infections and tumors. For the measurement of knee extension strength, additional exclusion criteria were severe back problems and knee or hip prosthesis.

In total, 947 participants were included in the present study. Of these participants, 770 were community-dwelling older adults (67% women), 104 were older adults living in assisted living facilities (76% women) and 73 were nursing home residents (71% women).

Outcome measurements

Functional performance

Six-minute walk test (6MWT)

The 6MWT was performed over a walking course of 20m. Participants walked up and down the course at a fast but comfortable pace, and the distance covered in 6 minutes (6MWD, in meters) was recorded (American Thoracic Society, 2002).

Modified Physical Performance test (mPPT)

Although the 6MWT has been shown to be a good indicator of functional performance in older adults (Bean et al., 2002), it only includes walking ability. The mPPT is a functional test battery that covers a broader range of functional items by also including upper extremity performance. The mPPT consists of nine functional items related to daily activities. Seven items were derived from the physical performance test described by Reuben and Siu (Reuben & Siu, 1990): (i) lifting a book from waist height to a shelf at shoulder level, (ii) putting on and taking off a coat, (iii) picking up a penny from the floor, (iv) turning 360°, (v) walking 15 m, (vi) ascending one flight of stairs, and (vii) climbing four flights of stairs. These seven items were combined with (viii) the chair rise test and (ix) the Romberg test for balance described by Guralnik and co-workers (1994). This modified version of the PPT has been used in previous research (Brown et al., 2000; Van Roie et al., 2011). The score of each item ranged from 0 (the inability to complete the task) to 4 (the highest level of performance), with a total mPPT score of maximum 36 points.

The mPPT was conducted in a subsample of older adults living in a residential care facility (102 of assisted living facilities and 50 of nursing homes), as the mPPT might not discriminate well between older adults who do not suffer from functional limitations (often perfect scores on sub-items).

Muscle strength

Handgrip strength

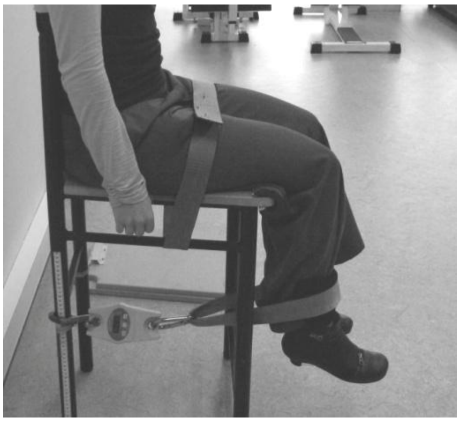
Handgrip strength was measured using a Jamar hand dynamometer, which was adjusted for hand size. The test-retest reliability of this test has been found to be high in older adults (ICC ≥0.85) (Wang & Chen, 2010). Handgrip strength (in kilograms) was measured twice with the dominant hand, in a standing position with the arm hanging by side and the elbow fully extended (Oja & Tuxworth, 1995). The best of both trials was used for further analyses. To standardize, the maximal static handgrip strength was expressed relative to body weight (GRIP/BW).

Knee extension strength

Lower extremity strength was measured using a digital Kern HCB dynamometer. A field test for isometric knee extension strength, inspired by the Physiological Profile Assessment, was designed (see Figure 1) (Lord, Menz, & Tiedemann, 2003). Previous research in our lab showed a high test-retest reliability for this field test in older adults (ICC =0.91–0.95) (data not published).

Participants were seated on a tall chair with the hip and knee joint angles positioned at 90°. The seating of the chair was adjustable dependent on the length of the participants' legs. The upper legs were stabilized with a safety belt. The dynamometer was attached to the rear leg of the chair to the distal end of the participants' tibia, using a strap perpendicular to the ground. The subjects were instructed to extend their leg as hard as possible against the strap, by building up strength gradually till maximal strength was reached. The right leg was tested, unless there was a medical contraindication (e.g., prosthesis). The test was performed twice and the best of both trials was used for further analyses. To standardize, the maximal static knee extension strength was expressed relative to body weight (KNEE/BW).

Figure 1. Knee extension strength test.



Statistical analyses

Descriptive statistics were presented as means ± SD. Comparisons between men and women and between settings were performed using unpaired t-tests.

Pearson correlation coefficients were calculated to determine the association between muscle strength and functional performance.

In addition, both muscle strength variables were entered in multiple forward stepwise regression models to determine the contribution of each variable to functional performance. Regression analyses were performed for the whole study sample and separately for the different settings.

Receiver operating characteristic (ROC) curves were obtained to define sex-specific cut-off values for GRIP/BW and KNEE/BW. Having functional limitations was defined as not being able to walk 400m during the 6MWT (Morley et al., 2011) and/or as having an mPPT-score below 32 (Van Roie et al.,

2011) (only in the subsample of 152 older adults living in a residential care facility). Cut-off values that yielded the best compromise between specificity and sensitivity were identified. All statistical tests were executed with SPSS software version 19. The level of significance was set at $p < 0.05$ (*).

RESULTS

The total study sample consisted of 301 men and 646 women. Descriptive statistics are summarized in Table 1.

Muscle strength variables as predictors of functional performance

Handgrip (r = 0.35–0.59) and knee extension strength (r = 0.50–0.63) were positively correlated with functional performance (6MWD and mPPT) in the different settings (p <0.05).

Both strength parameters were entered in stepwise regression to determine the contribution of each variable to functional performance. When both KNEE/BW and GRIP/BW were entered as predictor variables in a stepwise regression analysis with 6MWD as dependent variable (Table 2), KNEE/BW emerged as first significant predictor and explained 33% of the variance in functionality in the total study sample (β = 0.35, t = 10.33, p <0.001). GRIP/BW added only 6% to the explained variance (β = 0.34, t = 10.02, p <0.001) in the combined model. Nevertheless, both strength variables showed a similar contribution to 6MWD when included separately in the regression model (models 1 and 2). Similar results were found in the subsample of community-dwelling older adults and nursing home residents. Interestingly, in assisted living facilities, KNEE/BW proved to be a better predictor of 6MWD than GRIP/BW.

We additionally included regression analyses with mPPT as dependent variable. Table 3 shows that KNEE/BW is also a better predictor of the mPPT-score than GRIP/BW in assisted living facilities.

Table 1 .Sample characteristics.

		All subjects		Community		Assisted living facility		Nursing homes	
Variable		**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Female (%)		68.20		66.90		76.00		71.20	
Age (yr)		72.61	± 8.25	70.23	± 6.60†‡	81.97	± 5.97§	84.30	± 7.32*§
BMI ($kg \cdot m^{-2}$)		27.94	± 4.20	27.77	± 4.03	28.62	± 4.53	28.74	± 5.28
6MWD (m)		440.23	± 132.17*	486.06	± 87.24*†‡	262.33	± 107.39‡§	210.25	± 99.60*†§
GRIP/BW	♂	0.47	± 0.13*	0.49	± 0.11*†‡	0.36	± 0.09*§	0.32	± 0.14*§
	♀	0.32	± 0.10*	0.35	± 0.09*†‡	0.26	± 0.08*‡§	0.21	± 0.08* †§
KNEE/BW	♂	0.43	± 0.12*	0.45	± 0.11*†‡	0.36	± 0.10*§	0.32	± 0.11*§
	♀	0.33	± 0.11*	0.35	± 0.10*†‡	0.27	± 0.10*§	0.24	± 0.09*§
mPPT scores 0–36						26.69	± 6.70‡	17.04	± 7.51*†

Abbreviations: BMI = Body Mass Index; mPPT = modified Physical Performance test; 6MWD = 6-Minute Walk Distance (m); GRIP/BW = handgrip strength relative to body weight (kg/kg); KNEE/BW = knee-extension strength relative to body weight (kg/kg)

*Significantly gender effect ($p < 0.05$); male values higher compared with female values (except for age in nursing home residents)

† Significantly different from assisted living facility ($p < 0.05$)

§ Significantly different from community ($p < 0.05$)

‡ Significantly different from nursing home ($p < 0.05$)

Table 2. Regression analyses implementing three different sets of predictor variables (GRIP/BW only (1), KNEE/BW only (2), or the combination of both static strength tests (3)) for functional performance (6MWD).

Predictor variables		**Standardized β-coefficients**	**t**	**Partial R^2 values (R^2 change)**	**Adj. R^2 values for the set of predictors**
All subjects (n = 947)					
Model 1	GRIP/BW	0.58	21.59*		0.33
Model 2	KNEE/BW	0.58	21.79*		0.33
Model 3	(combined model)				0.40
	KNEE/BW	0.35	10.33*	0.33	
	GRIP/BW	0.34	10.02*	0.06	
Community (n = 770)					
Model 1	GRIP/BW	0.45	14.12*		0.21
Model 2	KNEE/BW	0.50	16.15*		0.25
Model 3	(combined model)				0.28
	KNEE/BW	0.36	9.22*	0.25	
	GRIP/BW	0.23	5.85*	0.03	
Assisted living facility (n = 104)					
Model 1	GRIP/BW	0.39	4.32*		0.15
Model 2	KNEE/BW	0.63	8.23*		0.39
Model 3	(combined model)				0.39
	KNEE/BW	0.63	8.23*	0.40	
	Excluded variable				
	GRIP/BW	*0.07*	*0.75*	-	
Nursing home (n = 73)					
Model 1	GRIP/BW	0.59	6.23*		0.34
Model 2	KNEE/BW	0.61	6.53*		0.37
Model 3	(combined model)				0.43
	KNEE/BW	0.39	3.33*	0.38	
	GRIP/BW	0.34	2.89*	0.07	

Note. Abbreviation: 6MWD = 6-Minute Walk Distance (m); GRIP/BW = handgrip strength relative to body weight (kg/kg); KNEE/BW = knee-extension strength relative to body weight (kg/kg).
* p <0.05

Table 3. Regression analyses implementing three different sets of predictor variables for physical performance (mPPT) in a subsample of older adults (assisted living facility and nursing home). In model 3, handgrip and knee extension strength were entered in a stepwise multiple linear regression.

Predictor variables		**Standardized β-coefficients**	**t**	**Partial R^2 values (R^2 change)**	**Adj. R^2 values for the set of predictors**
Assisted living facility (n = 102)					
<u>Model 1</u>	GRIP/BW	0.35	3.77*		0.12
<u>Model 2</u>	KNEE/BW	0.60	7.47*		0.35
<u>Model 3</u>	(combined model)				0.35
	KNEE/BW	0.60	7.47*	0.36	
	Excluded variable				
	GRIP/BW	*0.04*	*0.46*	-	
Nursing home (n = 50)					
<u>Model 1</u>	GRIP/BW	0.55	4.00*		0.28
<u>Model 2</u>	KNEE/BW	0.62	5.50*		0.37
<u>Model 3</u>	(combined model)				0.37
	KNEE/BW	0.62	5.50*	0.39	
	Excluded variable				
	GRIP/BW	*0.23*	*1.50*	-	

Note. Abbreviation: mPPT = modified Physical Performance Test; GRIP/BW = handgrip strength relative to body weight (kg/kg); KNEE/BW = knee-extension strength relative to body weight (kg/kg).
* p <0.05

<u>Functionally relevant cut-off value for muscle strength</u>

Both GRIP/BW and KNEE/BW significantly contributed to functional performance as measured by 6MWD and mPPT in the three settings. Therefore, the ROC method was used to determine sex-specific cut-off values for muscle strength below which functional limitations occurred. In our study sample, 27.7% (262 out of 947) was considered functionally limited (not able to walk 400m on 6MWT and/or mPPT-score < 32).

The cut-off value for KNEE/BW that yielded the best compromise between sensitivity and specificity was set at 0.40 (sensitivity = 0.81; specificity = 0.71) for men and at 0.31 (sensitivity = 0.76; specificity = 0.72) for women. For GRIP/BW, the cut-off value was set at 0.43 (sensitivity = 0.76; specificity = 0.73) for men and 0.31 (sensitivity = 0.80; specificity = 0.71) for women (Figure 2 and 3).

Figure 2. Receiver operating characteristic curves created for the identification of functional limitations based on handgrip strength (a) and knee extension strength (b) in men. The X-axis represents false positive rates and the Y-axis the true positive rates for each possible cut-off value. (■) represents the value yielding the best compromise between sensitivity and specificity. The area under the curve indicates a discriminative value of (a) 0.82 [95% CI 0.75–0.88] and (b) 0.83 [95% CI 0.77–0.90].

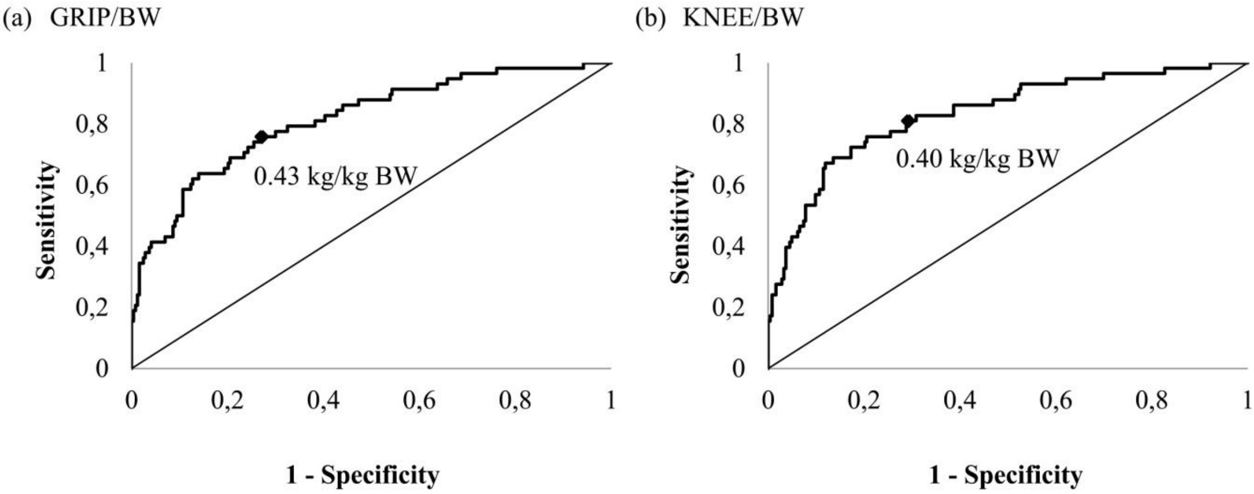
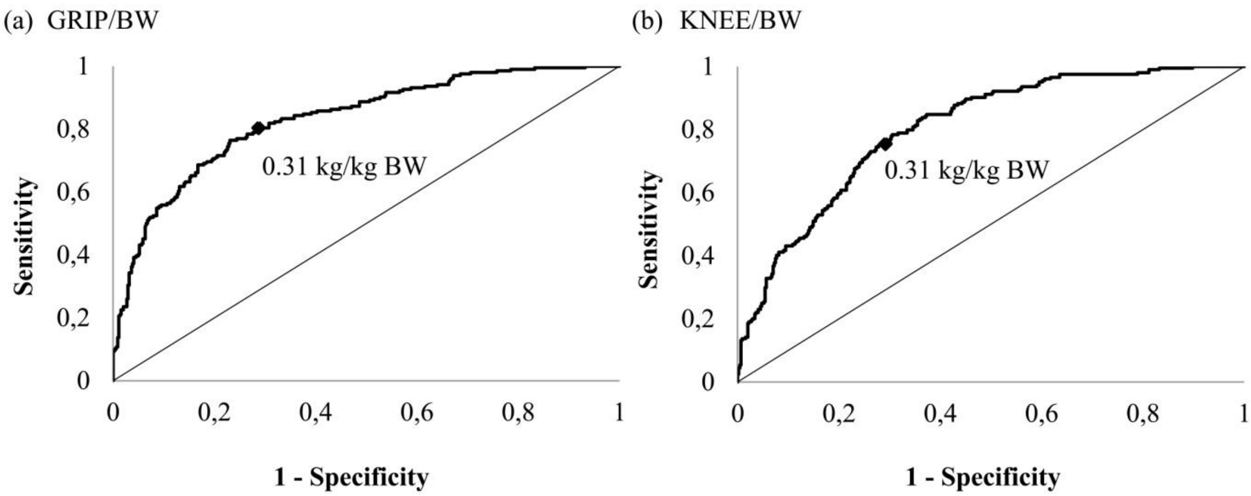


Figure 3. Receiver operating characteristic curves created for the identification of functional limitations based on handgrip strength (a) and knee extension strength (b) in women. The X-axis represents false positive rates and the Y-axis the true positive rates for each possible cut-off value. (■) represents the value yielding the best compromise between sensitivity and specificity. The area under the curve indicates a discriminative value of (a) 0.83 [95% CI 0.80–0.87] and (b) 0.80 [95% CI 0.77–0.84].



DISCUSSION

The first purpose of the current study was to examine whether static knee extension strength, measured with a simple field test, is a better predictor of functional performance in older adults than static handgrip strength. Results showed that knee extension strength was not able to predict functional outcomes better than handgrip strength in community-dwelling older adults and nursing home residents. However, knee extension strength was clearly more predictive than handgrip strength for functional performance in assisted living facilities.

The second purpose of this study was to identify cut-off values for knee extension strength below which older adults are more likely to have functional limitations. These cut-off values, expressed in kg per kg body weight, were 0.40 for men and 0.31 for women.

Muscle weakness is associated with functional decline in older adults (Lauretani et al., 2003; Marsh et al., 2011). In clinical practice and large-scale studies, muscle weakness is often screened by means of a handgrip strength test (Cruz-Jentoft et al., 2010; Morley et al., 2013). This test is preferred because of its simplicity and affordability. In our study, a positive correlation was found between handgrip strength and 6MWD (r = 0.59, p <0.001) and mPPT (r = 0.49, p <0.001), which confirms previous research (Legrand et al., 2013). There is no doubt that handgrip strength is well correlated with lower extremity strength (Bohannon et al., 2012; Samson et al., 2000; Tieland et al., 2014). The positive correlation between both strength measurements in our study (r = 0.67) supports the previously stated notion that they represent a common underlying construct (Bohannon et al., 2012).

However, the literature also suggests that using either of these tests alone is not enough to describe overall muscle strength (Bohannon et al., 2012). Given that the knee extensor muscles are considered primary movers in many functional tasks such as walking, chair rising and stair climbing (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002), it seems useful to additionally measure knee extension strength in older adults who are at risk for functional decline.

In the overall study sample, knee extension strength did not emerge as a better predictor of functional performance than handgrip strength. However, separate analyses for the different settings showed that knee extension strength might be clinically more relevant than handgrip strength in assisted living facilities. These facilities provide a housing and health care alternative to the community setting. Assisted living facilities combine independence with personalized supportive service to meet the needs of older adults in daily life activities. Individuals living in such facilities are often close to or just entering the early stages of functional limitations and are therefore an important target population for screening purposes (Van Roie et al., 2011). These early stages of functional limitations might be caused by clinically important declines in knee extension strength, which have been demonstrated to exceed declines in handgrip strength (Samuel et al., 2012).

To assess functional performance, the 6MWT was used in our study. This test has been shown to correlate with the performance of instrumental activities of daily life (Enright, 2003). However, it only evaluates a single item, i.e. walking ability, which is a performance measure of the lower limb. Instead of relying on a single item of walking ability, we also included a fuller assessment of functional abilities by means of the mPPT. Data of a subsample of residents in assisted living facilities and in nursing homes were available. Again, the results demonstrated the importance of knee extension strength over handgrip strength in functional performance in assisted living facilities. Therefore, knee extension strength could be a particularly useful indicator to screen for (future) functional limitations in older adults, especially in those who are at high risk for functional decline.

This study identified sex-specific functionally relevant cut-off values for knee extension strength, i.e., 0.40 kg/kg body weight for men and 0.31 kg/kg body weight for women. To the best of our knowledge, this study is the first to identify cut-off values for knee extension strength measured with the simple field test.

With regard to handgrip strength, cut-off values that have been frequently used in previous research are 30kg for men and 20kg for women (Lauretani et al., 2003). Our results indicate slightly higher cut-off values for men and women with an average body weight. More specifically, a man of 80kg and a woman of 70kg are considered to have muscle weakness when their handgrip strength values drop below 34.4kg and 21.7kg respectively. Part of the explanation for the higher cut-off value in our study is that grip strength has already been shown to be significantly greater in the standing position with the elbow fully extended than in other positions that are typically used (standing or sitting with the elbow flexed in 90°) (Liao et al., 2013).

An important question that needs consideration is whether clinicians should screen for muscle weakness using both or only one of the abovementioned static strength tests. Although screening for knee extension weakness is preferred because of its functional relevance, one should bear in mind that handgrip strength appears to be as predictive of functional performance as knee extension strength in community-dwellers and nursing home residents. In addition, handgrip strength tests are already well integrated in clinical practice. Another consideration is that more exclusion criteria are needed when evaluating knee extension strength in comparison with handgrip strength, which is a limitation of the knee extension test.

Instead of using only one strength test, our suggestion would be to use both field tests as screening tools. First, both strength tests do not identify the same individuals as functionally weak. If both cut-off values are combined as a “double check”, sensitivity to detect functional limitations increases up to 90%, indicating that more individuals are detected correctly as being functionally limited. Second, combining the cut-off values of both tests allows exercise interventions that are more adapted to the individual’s urgent needs, with more focus on lower or upper body function.

Aside from screening purposes, the static knee extension strength test might also be used to evaluate age- and training-related adaptations in large-scale studies among older adults. For these purposes, the evaluation of knee extension strength might be preferred over handgrip strength because of the following reasons. First, knee extension strength shows a steeper decline than handgrip strength with aging (Newman et al., 2003; Samuel et al., 2012). Second, handgrip strength does not provide a valid tool to evaluate the efficacy of exercise intervention programs to increase muscle mass or strength in an elderly population, as such exercise programs often focus on lower body exercises (Tieland et al., 2014).

The following limitations of the present study should be taken into account. A first limitation is the cross-sectional study design, which precludes causal relationships between muscle strength and functional performance. However, previous longitudinal research already confirmed that low muscle strength is likely to cause functional limitations (Hicks et al., 2012; Rantanen et al., 1999; Rantanen et al., 2001). A second limitation is that the present field test for knee extension strength tends to underestimate static strength when compared to the golden standard (Biodex dynamometer, data not published). However, a high test-retest reliability for this field test has been shown in a sample of older adults (ICC = 0.91-0.95, data not published). A third limitation is that only static strength measurements were included in our study. Previous studies already showed that dynamic strength, power and speed of movement of the knee extensors might be more important for functional performance of older adults (Van Roie et al., 2011). It should be noted however that up till now, no standardized and easy-to-use measurement is available for these dynamic strength and power evaluations.

CONCLUSION

The results of the present study demonstrate that handgrip and knee extension strength are important predictors of functional performance in older adults. Only in assisted living facilities, knee extension strength was clearly a better predictor of functional performance than handgrip strength. This study also identified muscle weakness cut-off values for handgrip and knee extension associated with functional limitations defined by 6MWD and/or mPPT. Both cut-off values appear to be highly sensitive to screen for functionally relevant muscle weakness in older adults. Early identification of high risk individuals may create opportunities for developing and implementing strategies to counteract disability.

ACKNOWLEDGEMENTS

We would like to acknowledge the Policy Research Centre on Sports, supported by the Flemish Government and the Research Foundation Flanders, Belgium (FWO-Vlaanderen) for their financial support.

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CHAPTER 3

Interventions to promote physical activity in older adults living in assisted living facilities

Paper 4 Short- and long-term effects of 10-week cycle ergometer interventions for older adults in assisted living facilities

Short- and long-term effects of 10-week cycle ergometer interventions for older adults in assisted living facilities

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Submitted to *Journal of Aging and Physical Activity*

ABSTRACT

Background: This study evaluated the short- and long-term effectiveness of a 10-week cycle ergometer intervention on physical activity (PA), functionality and muscle strength in older adults.

Methods: Eight assisted living facilities (n=95; 82.1±5.9 years) were randomly assigned to (1) structured coaching (STRUC), consisting of three weekly supervised sessions on a cycle ergometer, (2) autonomy-supportive coaching based on the Self-Determination Theory (AUT), consisting of an individualized cycle ergometer program with minimal coaching contact, or (3) a control group (CON). Measurements were performed at baseline, post-intervention (10 weeks after pre) and at follow-up (24 weeks after post).

Results: Adherence to the 10-week program was higher in STRUC compared to AUT. However, in the long-term, adherence rates were similar, although training volume was higher in STRUC.
Self-reported moderate intensity PA increased more from pre to post in STRUC and AUT compared to CON ($P<.05$). However, only AUT showed short-term gains in daily energy expenditure. Adherers (≥80% of training sessions from pre to post) showed better short-term results on functionality and muscle strength.

Conclusion: Minimal contact with a coach is sufficient to promote cycle ergometer use, but training volumes are higher when training is strictly supervised.

Keywords: stationary bicycle exercise; aging; physical performance; Self-Determination Theory

INTRODUCTION

Populations around the world are aging rapidly. The fastest growing segments are the old (75-84 years) and old-old, i.e., those being 85 years and older (Christensen et al., 2009). Human aging is characterized by declines in muscle strength and physical fitness, threatening the independency and quality of life of older adults (Spirduso, Francis, & MacRae, 2005). Participation in regular physical activity (PA) has been shown to reduce the impact of aging. More specifically, regular PA has been associated with a decreased risk for disability, chronic diseases (e.g. cardiovascular diseases, diabetes mellitus, obesity, hypertension, osteoporosis) and morbidity (Mazzeo et al., 1998; Warburton, Nicol, & Bredin, 2006). Despite all this evidence, a large proportion of the older population is not regularly involved in PA (Gisle et al., 2010). Moreover, PA in older adults declines more rapidly with increasing age (Buchman et al., 2014). Therefore, the promotion of PA should be considered as a public health priority in older adults.

Consequently, the number of PA intervention studies in older adults has been increasing rapidly. Different reviews suggest that interventions designed to increase PA behavior among older adults can be effective, although changes are relatively small and short-lived (Chase, 2014; Conn et al., 2003; van der Bij, Laurant, & Wensing, 2002). Traditional PA interventions for older adults were structured, included strict supervision by a coach, and were fitness center oriented. Such interventions have the advantage that the volume and intensity of training can be controlled. However, their implementation possibilities are limited because they require a lot of organization, qualified staff, time and financial support. Moreover, it is not clear whether positive effects can be maintained in the long-term, when supervision is no longer available (Conn et al., 2003; Taylor et al., 2004; van der Bij, Laurant, & Wensing, 2002). In order to facilitate PA promotion in the wider community, the effectiveness of less demanding procedures should be studied.

In addition, interventions based on counseling procedures with a theoretical basis tend to show larger effects than non-theoretically based interventions (Chase, 2014). In the past decade, the Self-Determination Theory (SDT) has been postulated as a promising theoretical approach to facilitate behavioral change in PA, especially in the long term (Chatzisarantis & Hagger, 2009). This theory assumes that people possess three psychological needs; the need for autonomy, the need for relatedness and the need for competence. Need-supportive environments foster autonomous motivated behavior, which is assumed to yield more (long-term) engagement in behavior change (Ryan & Deci, 2000; Teixeira et al., 2012). SDT-based PA interventions have been successfully applied in community-dwelling older adults (Van Hoecke et al., 2014). However, to our knowledge no studies have incorporated SDT principles among older adults living in assisted living facilities, where functional capacity may be impaired (Teixeira et al., 2012).

Over the last two decades, assisted living facilities have rapidly emerged as housing option for older adults (Agentschap Zorg en Gezondheid [Agency for Care & Health], 2010; Schulz et al., 2006). Assisted living combines independence with personalized supportive care to meet the needs of older adults in daily life activities. In assisted living facilities, residents are often close to or just entering the early stage of physical impairments (Giuliani et al., 2008). This population is of particular interest for PA promotion because regular PA slows down the disablement process (Tak et al., 2013). To date, virtually no PA intervention studies included older adults living in assisted living facilities.

Considering the high risk for injury and falls in this population, ergometer cycling might provide a feasible type of PA. Ergometer cycling involves low impact movement and trains the cardio-respiratory system as well as lower body muscles, which are important for many daily life activities (Hughes, Myers, & Schenkman, 1996; Ploutz-Snyder et al., 2002).

The current study consists of a 10-week cycle ergometer intervention for older adults in assisted living facilities. Two coaching procedures were compared: structured coaching with permanent assistance and coaching with minimal coaching contact. The latter coaching procedure used SDT-embedded coaching techniques, with specific attention for the need for autonomy. Both short- and long-term effects of the intervention on PA, muscle strength and functional performance were investigated and compared with a control condition. We hypothesized that both intervention groups would increase PA in the short-term. In addition, we expected that the autonomy-supportive coaching would be more effective in the long-term.

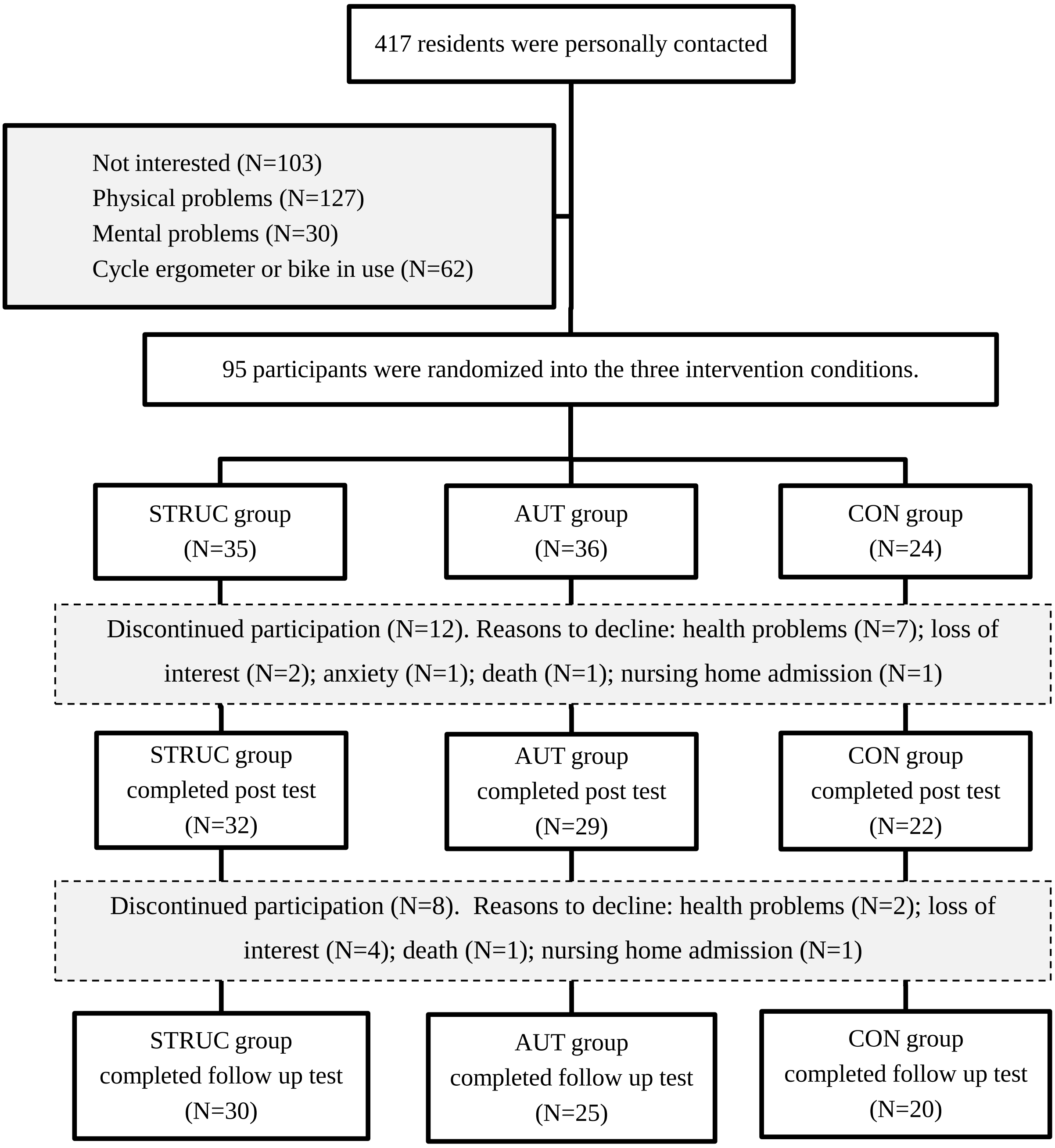
METHODS

Participants

A flow chart of the study is provided in Figure 1. Between October and December 2012, 417 residents of 8 assisted living facilities were personally contacted to participate in the study. The randomly selected assisted living facilities were located in Flanders/Belgium and housed at least 35 residents. In the facilities, residents live in independent units, but are offered a broad range of services (meals, house-cleaning, etc.). Twenty-five percent of residents was not interested and 53% was excluded according to the exclusion criteria. Exclusion criteria were (i) cognitive impairment as diagnosed by the general practitioner, (ii) any specific contra-indication for participation in the cycle ergometer program or in the physical measurements in the opinion of the general practitioner (e.g., severe thrombotic or neurological disease; recent cardiovascular event or serious lung-, heart- or vascular disease; uncontrolled hypertension or diabetes mellitus; infection or tumor; and a major fracture in the past four months), and (iii) systematic exercise on a bike or cycle ergometer at the moment of recruitment. All procedures were approved by the human Ethics Committee of KU Leuven.

In total, 95 residents gave written informed consent. Randomization took place at facility level and was stratified for number of residents per facility. The 8 assisted living facilities were assigned to one of the three following conditions: a structured group with permanent assistance (STRUC; N=3), an autonomy-supportive group with minimal contact (AUT; N=3) or a control group (CON; N=2). The control group included two instead of three assisted living facilities, as we expected less drop-out in comparison with the interventions groups.

Figure 1. Study design



Interventions

In both intervention groups, cycle ergometers were placed in a common area (e.g. cafeteria) of the assisted living facility so that the ergometers were easily accessible for all participants.

Structured coaching (STRUC)

The STRUC coaching group exercised three times weekly on a cycle ergometer, on nonconsecutive days for a period of 10 weeks (total of 30 sessions). Training sessions were scheduled for each participant and were closely supervised by a trained fitness coach. Training volume for week 1 was based on an initial test on the cycle ergometer. In this test, participants were instructed to pedal for 6 minutes on a Kettler® ergometer at a fast but comfortable pace, taking rest periods if necessary. Perceived exertion was assessed immediately upon exercise cessation using the Borg scale (Pollock et al., 1998). Initial training volume was based on the total pedal minutes of the initial test and the perceived exertion (Table 1).

Table 1. Training volume (minutes/session)

INITIAL TRAINING VOLUME			
Initial cycle ergometer test			Training volume per session week 1
6 minutes	Borg <11	⇨	6 + 4 minutes
	≥11 Borg <13	⇨	4 + 4 minutes
	Borg ≥13	⇨	4 + 2 minutes
<6 minutes	≥3 minutes	⇨	4 + 2 minutes
	≤3 minutes	⇨	2 + 2 minutes

➔

TRAINING VOLUME NEXT WEEKS		
End of training week x		Training volume per session week x + 1
Borg ≤11	⇨	training volume per session week x **+ 2 minutes**
Borg >11	⇨	training volume per session week x

According to the American College of Sports Medicine (ACSM), intensity of aerobic training in older adults should be 40-60% of heart rate reserve, corresponding to 11-13 on the Borg scale (Mazzeo et al., 1998). Therefore, the gradual increase in training volume was dependent on participants' perceived exertion. More specifically, only if participants indicated that the exercise intensity of the last training week was rather "light" (or less) (corresponds to a Borg score ≤11), 2 minutes were added to the training volume of each session of the next week (Table 1). The main objective of the cycle ergometer program was to support the participants to attain the recommended level of 30 minutes of moderate intensity PA per week (Nelson et al., 2007). As suggested by ACSM, the frequency and duration (training volume) of an activity is more important than the intensity at the beginning of a program. Therefore no increase in intensity was assumed in the present study (Mazzeo et al., 1998).

Autonomy-supportive coaching (AUT)

The autonomy-supportive coaching program consisted of a limited number of contact moments (i.e., four 1-hour contacts in 10 weeks) between the coach and the participant. Contact moments took place two to three weeks after the previous contact. An easily accessible individualized cycle ergometer program consisting of weekly schedules was provided to the participants. Training volume was similarly prescribed as for STRUC (Table 1) and the coach suggested a training frequency of 3 times weekly, on nonconsecutive days.

During the first face-to-face contact, the coach explained the individualized program and asked for expectations and previous experience (history of cycling). During the other contact moments, the degree of adherence to the program was evaluated and the coach identified barriers and suggested solutions. The coach motivated the participants to persist in the program by coaching according to the principles of the Self-Determination Theory (Ryan & Deci, 2000). The coach tried to create a need-supportive environment by providing competence support (e.g., positive feedback, encourage participants to progress through the different week schedules according to their individual abilities), by providing relatedness (e.g., active listening, encourage to exercise with peers), and especially by stimulating autonomy (e.g. letting the participants make decisions, counteract dependency from coach to make participants self-supportive). Especially the autonomy-component considerably differed between both intervention groups as participants in STRUC also received competence support (e.g., positive feedback, progress in training volume) and relatedness support (e.g., presence of the coach and significant others). With regard to the autonomy-component, participants in AUT had to complete the program on their own and they could choose when and with whom they exercised.

Control group (CON)

CON did not receive PA instructions, nor a cycling ergometer program.

<u>Follow-up period</u>

After the intervention, the cycle ergometer remained available in the intervention-assisted living facilities and residents were offered the opportunity to continue training. STRUC and AUT were encouraged to continue their individualized cycle ergometer program. However, no contact took place between coach and participants between post and follow-up tests.

Outcome measurements

All participants completed measurements before (pre), immediately after the intervention (post) and 6 months after post-test measurements (follow-up). All measurements were conducted by a single investigator at the assisted living facility where the participants resided.
Participants attended two testing days, separated by one week. Usual walking aids were allowed for all tests. On the first day (1) height and weight, (2) training volume for week 1 (Table 1) and (3) lower extremity strength were assessed. On the second day, all residents participated in two additional measurements: (4) Functional exercise capacity was measured using the 6-minute walk test (6MWT) and (5) functional performance was scored using the modified Physical Performance Test (mPPT).

Functional performance

Six-minute walk test (6MWT)

The 6MWT was performed over a walking course of 20m. Participants walked up and down the course at a fast but comfortable pace, and the distance covered in 6 minutes (6MWD, in m) was recorded (American Thoracic Society, 2002). During this test, step length (in cm) was also determined. The distance of ten steps was measured and divided by 10.

Modified Physical Performance test (mPPT)

The mPPT is a performance-based measure of functionality related to daily activities. This test consists of nine functional items related to daily activities: (i) lifting a book, (ii) putting on and taking off a coat, (iii) picking up a penny, (iv) turning 360°, (v) the chair rise test, (vi) ascending one flight of stairs, and (vii) climbing four flights of stairs, (viii) walking 15 m and (ix) the progressive Romberg test for balance (Brown et al., 2000). The score of each item ranges from 0 (the inability to complete the task) to 4 (the highest level of performance), with a total mPPT-score of maximum 36 points.

Muscle strength

Isometric knee extension strength was measured using a digital Kern HCB dynamometer. Participants were seated on an adjustable chair with the knee and hip joint angles at 90°. The upper legs were stabilized with a safety belt. The dynamometer was attached to the rear leg of the chair and to the distal end of the tibia, using a strap perpendicular to the ground. The participants had to extend their leg as hard as possible against the strap (Martien et al., 2014). The test was performed twice, and the highest score was recorded for further analysis. The right leg was tested, unless there was a medical contraindication (knee or hip prosthesis).

Physical activity

Subjectively measured physical activity

Self-reported PA, expressed in minutes/week, was measured with a modified version of the Physical Activity Scale for Elderly (Washburn et al., 1993). Participants were asked to recall the number of days per week and the number of hours per day they had spent in light (e.g. slow walking [during leisure time and for transportation], petanque, exercises at home), moderate (e.g. cycling, swimming, gardening) and vigorous (e.g. running) intensity PA in a typical week during the past month.

Objectively measured physical activity

The wireless monitors Sensewear Pro (SWPro) and Mini (SWMini) (Bodymedia Inc., Pittsburgh, PA, USA) were used to estimate energy expenditure (EE; expressed in kcal/min), and objectively measured minutes of light and moderate intensity PA (expressed in min/week). Both devices were used because of practical reasons. Participants were randomly given a SWPro or SWMini, except those participants that had a cardiac pacemaker (n=10). To avoid interference with the pacemaker, participants were given a SWPro when the cardiac pacemaker was inserted in the left subclavicular region, as the SWPro is worn over the right triceps. Participants having a pacemaker inserted in the right subclavicular region were given a SWMini, worn over the left triceps. The monitor estimates EE and metabolic equivalents (METs) minute-by-minute through automatically applied algorithms developed by the manufacturer. MET-values were used for the classification of exercise intensity. According to commonly-applied PA recommendations by ACSM for older adults >80y, the following MET cut-points were used to define light and moderate intensity PA in the present study: ≥1MET <2MET (light intensity PA) and ≥2MET (moderate intensity PA) (Pollock et al., 1998).

Participants were instructed to wear the multisensor for 24 hours on 7 consecutive days (except during bathing activities). A valid day was considered as a day with at least 1368 min of SW data, which corresponds to a wearing time of 95%. Days below that threshold were excluded from analyses. Analyses showed a significant difference in EE between Sunday and the other days of the week (P<.05). Therefore, in order to be included in the analyses, participants needed valid data of Sunday and at least 3 other days. Approximately 80% (75 out of 95) of the participants had complete SW-data at baseline. Complete datasets were available for 47 and 38 participants at post and follow-up test respectively.

Adherence to the program and fall history

All participants were asked to report the occurrence of fall events on a calendar from pre to follow-up. Participants in STRUC and AUT were also required to record their training sessions on the cycle ergometer. Adherences rates were calculated as the number of training sessions divided by the recommended training frequency and multiplied by 100. Frequency recommendation from pre to post was 30 (3x/week for 10 weeks), and from post to follow-up 72 times (3x/week for 6 months).

Statistical analyses

Data were analyzed using SPSS software version 22.0 (Chicago, IL). For all analyses, the significance level was set at $P<.05$. Descriptive statistics were presented as means ±SD. Comparisons between men and women were performed using unpaired t-tests. A chi-square test was used to test for differences in dropout rates and percent falls between the groups.

Between-group differences for baseline variables were analyzed by one-way analysis of variance with Bonferroni post hoc testing. Within-group changes from pre to post and from pre to follow-up for all outcome variables were analyzed with paired T-tests.

To assess between-group differences in changes over time for all outcome variables, linear mixed-model analyses with an unstructured covariance structure (time as repeated factor and group as fixed factor), were used. Post hoc analyses were conducted to determine differences in changes between groups.

To compare adherers and non-adherers, participants were divided into two categories in terms of their adherence rate from pre to post. The first category is adherers, i.e. participants of STRUC or AUT who adhere to at least 80% of the prescribed number of training sessions. The second category is non-adherers, i.e. participants of STRUC or AUT with an adherence rate <80% and the CON group.

RESULTS

Baseline characteristics

Baseline characteristics are reported in Table 2. No significant baseline differences were detected between groups for any of the variables (all $P>.05$).

Dropout

The number of and the reasons for dropouts are shown in Figure 1. Chi-square analysis showed that the dropout rates were not significantly different between the three groups. There was a dropout of 12.63% from pre to post and of 9.64% from post to follow-up. The most frequently reported reason was health problems. Dropout analyses revealed significant baseline differences between participants who completed post-tests and dropouts. Dropouts scored significantly lower for 6MWD ($P=.003$), mPPT ($P=.003$) and for knee extension strength ($P=.030$). Moreover, participants who dropped out at follow-up were older ($P=.033$) and more functionally dependent (mPPT; $P=.008$) than those who completed follow-up.

Adherence

Table 3 shows the adherence to the cycle ergometer program for participants who completed the 10-week intervention period. During the intervention period, the STRUC group exercised significantly more on the cycle ergometer in comparison with the AUT group (adherence rate: P=.001; sessions per week: P=.001; minutes per session: P=.021). After the intervention period, adherence rate and training frequency significantly decreased in both groups, with no difference between STRUC and AUT. However, 56.7% of STRUC and 60.0% of AUT continued to exercise on the cycle ergometer with an adherence rate of at least 20% (15 trainings sessions over 6 months). Moreover, 26.7% (8 out of 30 participants) and 20.0% (5 out of 25 participants) of STRUC and AUT respectively had an adherence rate ≥80% during follow-up period. Interestingly, training volume significantly increased from pre to follow-up in both intervention groups. Participants in STRUC had a higher training volume during the intervention period (P=.021) and during follow-up period (P=.001) in comparison with AUT (Table 3).

Table 2. Means (±SD) or percentage for some demographic characteristics at baseline.

	Total (N=95)		STRUC (N=35)		AUT (N=36)		CON (N=24)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (years)	82.12	5.92	81.49	5.78	81.57	6.76	83.88	4.46
Gender (% females)	76.84		68.57		80.56		83.33	
Body Mass Index (kg/m^2)	28.82	4.56	28.53	4.43	29.46	4.53	28.28	4.87
6MWD (m)	269.44	106.91	267.74	121.92	264.69	107.87	279.04	83.05
mPPT (/36)	26.82	6.98	27.26	6.79	26.33	6.81	26.92	7.74
Knee extension strength (kg)	21.69	8.83	22.23	9.24	21.78	9.92	20.76	6.47

Note. 6MWD=6 minute walk distance; mPPT=modified Physical Performance Test

Table 3. Cycle ergometer use during the 10-week intervention period and during the 6-month follow-up period for both intervention groups.

		10-week period between pre and post				6-months period between post and follow-up				t-value
		N	*Mean*	*±SD*	*Min – Max*	*N*	*Mean*	*±SD*	*Min – Max*	
STRUC	Adherence rate	32	89.17§	13.14	40.00 – 100.00	30	44.12	42.41	0.00 – 119.44	6.12**
	Exercise sessions per week[a]	32	2.68§	0.39	1.20 – 3.20	21	1.89	1.11	0.17 – 3.58	3.59*
	Minutes per session[a]	32	13.04§	4.23	5.57 – 23.24	21	20.50§	8.18	6.00 – 30.53	–4.92**
AUT	Adherence rate	29	68.16	31.29	13.33 – 130.00	25	42.89	48.78	0.00 – 200.00	3.33*
	Exercise sessions per week[a]	29	2.04	0.94	0.40 – 3.90	20	1.61	1.47	0.13 – 6.00	2.51*
	Minutes per session[a]	29	10.55	3.96	4.96 – 18.22	20	12.84	5.88	4.00 – 25.00	–2.24*

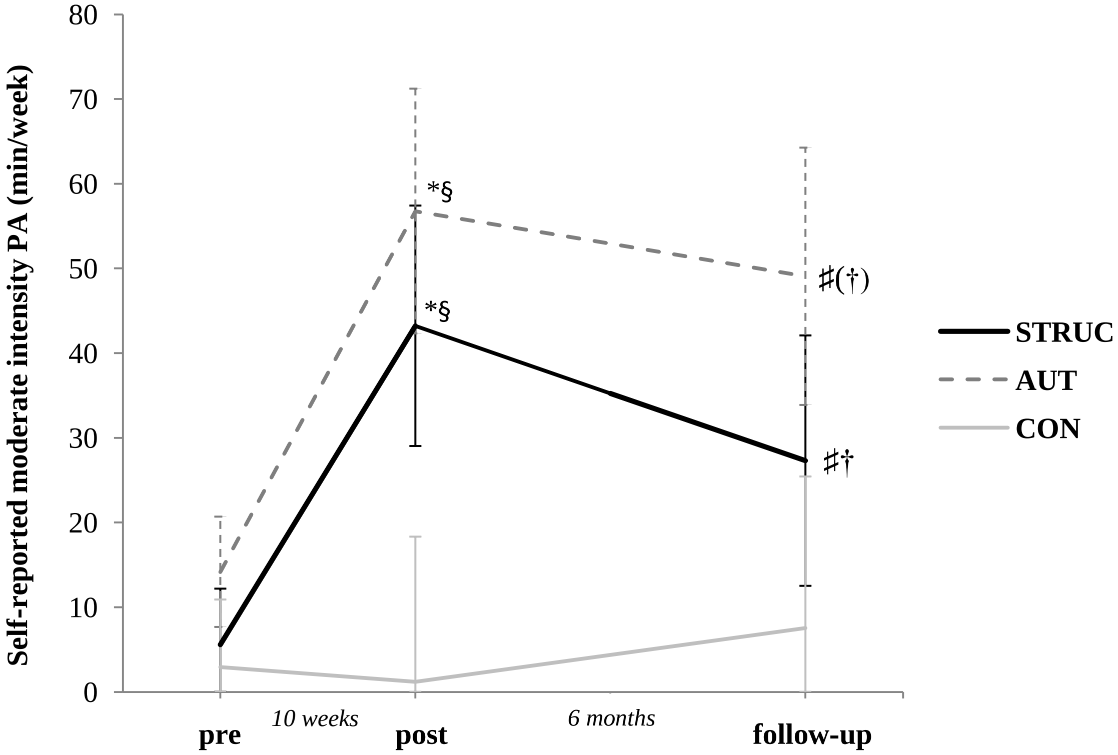
Note. [a]Mean values for those participants who exercised on the cycle ergometer.
*Significant difference between the 10-week and 6-month period (*P<.05; **P<.001)
§Significant difference with AUT

Physical activity

Self-reported PA (Table 4 and Figure 2)

Neither a time nor a time-by-group interaction effect was found for self-reported light intensity PA. However, a significant time-by-group interaction effect was found for moderate intensity PA. More specifically, from pre to post, STRUC and AUT increased significantly more in comparison with CON. Moreover, paired t-tests showed a significant increase in self-reported moderate intensity PA from pre to follow-up for STRUC (P=.014) and a trend toward a significant increase for AUT (P=.055). However, no significant time-by-group interaction effect with CON group was found from pre to follow-up. None of the residents participated in vigorous intensity PA.

Figure 2. Changes over time in self-reported moderate intensity physical activity; expressed in minutes per week (±SE) in the STRUC, AUT and CON groups.



*Significant change from pre to post; †from pre to follow-up (P<.05)
§Significant interaction effect pre post (time x group) with CON (P<.05)
♯Significant interaction effect post fu (time x group) with CON (P<.05)

Objectively measured activity (Table 4)

A significant time-by-group interaction effect was found for total EE, with a higher increase from pre to post in AUT compared to CON. In addition, for objective moderate intensity activity on a weekly basis, AUT increased more from pre to post as compared to both STRUC (P=0.007) and CON (P=0.001). However, these differences disappeared at follow-up.

Physical fitness and functionality

Despite the positive effects on PA and cycle ergometer use, no significant time-by-group interaction effects were found for 6MWD, mPPT, knee extension strength or step length. With regard to percent fallers, analyses revealed neither significant differences between groups nor significant changes over time (all P>.05). Paired t-tests only revealed a significant increase from pre to post in 6MWD (+11.70±5.70%; P=.024) and mPPT (+5.77±2.54%; P=.042) in the STRUC group and a significant decrease from pre to post in knee extension strength (–5.58±3.96%; P=.043) in the CON group. These changes were no longer significant at follow-up. For step length only, a significant increase was found from pre to follow-up in STRUC (+6.65±8.00%; P=.006; Table 4).

When comparing adherers (participants of STRUC or AUT with an adherence rate ≥80% during the intervention period) with non-adherers (adherence rate <80% and CON group), a significant time-by-group interaction effect was found for step length and mPPT; and a trend towards a significant time-by-group interaction effect was found for knee extension strength (Table 5). More specifically, adherers showed a greater increase from pre to post for mPPT and from pre to follow-up for step length, whereas non-adherers showed a greater decrease from pre to post for knee extension strength.

Table 4. Estimated means (SE) at pre, post and follow-up for the three groups for physical activity behavior, physical fitness and functionality.

	Pre	Post	Follow-up	F-value time (P-value)	F-value time x group (P-value)
		Self-reported PA			
Total light intensity PA (min/week)					
STRUC	346,19 (58,15)	327,35 (48,70)	362,24 (59,23)		
AUT	285,17 (57,09)	224,93 (49,34)	292,23 (60,63)	0,81 (.450)	1,02 (.403)
CON	158,85 (69,92)	212,70 (58,78)	195,87 (71,80)		
Total moderate intensity PA (min/week)					
STRUC	5,57 (6,61)	43,21 (14,20)*§	27,29 (14,79)♯†		
AUT	14,17 (6,51)	56,76 (14,45)*§	49,06 (15,19)♯(†)	**7,97 (.001)**	**2,72 (.034)**
CON	2,92 (7,98)	1,18 (17,13)	7,53 (17,90)		
		Objectively measured activity			
Energy expenditure (kcal/day)					
STRUC	1848,71 (58,79)	1863,67 (57,94)	1818,68 (52,77)		
AUT	1840,76 (56,81)	1921,32 (55,79)*§	1803,84 (52,11)‡♯	**3,32 (.046)**	**3,26 (.020)**
CON	1823,69 (69,20)	1755,50 (69,13)	1768,84 (65,42)		
Light intensity activity (minutes/week >1MET <2MET)					
STRUC	1431,06 (149,82)	1574,42 (157,51)	1291,83 (161,27)♯¥		
AUT	1046,33 (144,76)	1081,22 (150,18)	1261,38 (161,64) †	0,32 (.731)	2,34 (.069)
CON	1632,76 (177,31)	1612,11 (193,98)	1767,45 (210,44)		
Moderate intensity activity (minutes/week ≥2MET)					
STRUC	1000,75 (112,27)	996,48 (129,67)¶	997,54 (148,98)¥		
AUT	940,05 (108,39)	1196,44 (124,70)*§	860,74 (148,21)♯	1,45 (.247)	**4,63 (.004)**
CON	1115,87 (132,19)	1008,62 (155,20)	1077,19 (188,05)		
		Physical fitness and functionality			
6MWD (m)					
STRUC	267,74 (17,95)	285,36 (18,57)*	281,54 (19,79)		
AUT	264,69 (17,70)	262,78 (18,68)	253,60 (19,85)	1,85 (.165)	1,22 (.309)
CON	279,04 (21,68)	282,69 (22,53)	270,64 (24,03)		
mPPT (/36)					
STRUC	27,26 (1,17)	28,49 (1,17)*	27,01 (1,23)‡		
AUT	26,33 (1,16)	26,11 (1,17)	26,20 (1,24)	2,98 (.057)	1,21 (.312)
CON	26,92 (1,42)	27,70 (1,41)	26,36 (1,50)		
Knee extension strength (kg)					
STRUC	22,23 (1,55)	22,26 (1,58)	21,62 (1,70)		
AUT	21,78 (1,53)	21,02 (1,57)	21,43 (1,70)	2,20 (.119)	0,96 (.437)
CON	20,76 (1,87)	19,23 (1,90)*	19,64 (2,05)		
Step length (cm)					
STRUC	50,34 (1,83)	51,20 (2,09)	52,89 (2,16)†		
AUT	51,21 (1,80)	50,50 (2,10)	51,42 (2,06)	0,93 (.401)	1,95 (.113)
CON	50,22 (2,21)	51,38 (2,55)	49,87 (2,50)		

*Note.*PA=physical activity; 6MWD=6 minute walk distance; mPPT=modified Physical Performance Test
*Significant change from pre to post; †pre to follow-up; ‡post to follow-up (P<.05)
§Significant interaction effect pre post (time x group) with CON (P<.05)
¶Significant interaction effect pre post (time x group) with AUT (P<.05)
♯Significant interaction effect post fu (time x group) with CON (P<.05)
¥Significant interaction effect post fu (time x group) with AUT (P<.05)

Table 5. Means (±SD) at baseline and percent changes (±SD) compared to pre at post and follow-up for physical fitness and functionality in adherers (adherence rate ≥80%; N=45) and non-adherers (adherence rate <80% and CON group; N=38).

Outcome measures		Pre	% change from pre to post	% changes from pre to follow-up	F-value time (P-value)	F-value time x group (P-value)
Step length (cm)	Adherers	52,98 ± 1,26	+2,31 ± 11,23	+6,48 ± 10,92†§	1,58 (.214)	**5,10 (.009)**
	Non-adherers	50,16 ± 0,92	–0,65 ± 10,57	–2,08 ± 7,79		
6MWD (m)	Adherers	293,55 ± 124,61	+9,74 ± 29,47*	+6,68 ± 27,40	1,46 (.240)	1,14 (.324)
	Non-adherers	270,36 ± 84,08	+0,45 ± 19,07	–2,46 ± 13,85		
mPPT (/36)	Adherers	27,76 ± 6,77	+6,91 ± 13,79*§	+0,68 ± 13,12‡	3,04 (.054)	**3,19 (.047)**
	Non-adherers	27,15 ± 6,50	–0,03 ± 14,44	–2,92 ± 14,72		
Knee extension strength (kg)	Adherers	23,79 ± 9,06	+1,73 ± 14,22§	–4,59 ± 20,86	1,86 (.164)	3,04 (.054)
	Non-adherers	21,28 ± 7,26	–6,44 ± 14,72*	–4,06 ± 16,14		

Note. 6MWD=6 minute walk distance; mPPT=modified Physical Performance Test.
*Significant change from pre to post; †from pre to follow-up; ‡from post to follow-up (P<.05)
§Significant difference with non-adherers (P<.05)

DISCUSSION

The purpose of the present study was to examine the short- and long-term effects of a 10-week cycle ergometer intervention on PA, physical performance and muscle strength in older adults. Two coaching procedures were compared: (1) structured coaching with permanent assistance and (2) coaching with a limited number of contact moments and specific attention for the need for autonomy (i.e., residents completed the program on their own and they could choose when and with whom they exercised).

A specific cycle ergometer training program with different starting levels was designed for older adults living in assisted living facilities. A first notable result of the current study is that ergometer cycling seems feasible in this functionally limited age-group. Training sessions were experienced as pleasant by virtually all participants and facilities were satisfied with the intervention. Moreover, with regard to large-scale implementation, almost all facilities decided to purchase a cycle ergometer after the follow-up measurements. Importantly, older adults in assisted living facilities can be motivated by a coach to start exercising on a cycle ergometer. As shown in the results section, STRUC and AUT exercised on average 2.68 and 2.04 times per week on the cycle ergometer during the 10-week intervention period. Even though STRUC exercised more than AUT during the intervention, minimal-contact coaching can still stimulate older adults to start a cycle ergometer program, which is in line with other PA interventions in older adults (Opdenacker et al., 2008; Van Hoecke et al., 2014). However, it should be noted that more assistance and structure given by a coach during the initial period (=STRUC) resulted in higher adherence rates and higher training frequency and volume.

Even more important to investigate is whether older adults continue exercising after cessation of a supervised intervention. Here, we hypothesized that AUT would yield larger long-term effects in comparison with STRUC as coaching in AUT was more need-supportive during the intervention period. Previous studies had shown that more need-support results in more autonomous engagement in PA and consequently in more long-term engagement after an intervention period (Opdenacker et al., 2008; Van Hoecke et al., 2014). In contrast with our hypothesis, no differences between STRUC and AUT were found on long-term adherence rates. In this regard, it should be noted that the coach in STRUC might have provided competence support (e.g. positive feedback, progress in training volume) and relatedness support (e.g. participants exercised together with other residents and the coach was always nearby) as well. The only difference in both intervention groups was the autonomy-component. Participants in AUT had to complete the program on their own, whereas participants in STRUC were closely supervised by the coach. However, it seems that stimulating autonomy in this age group does not result in higher long-term adherence rates, which is in contrast with intervention studies in younger individuals. Moreover, strict supervision seems more effective in older adults considering that the training volume in STRUC (e.g. training minutes per session) was significantly higher in comparison with AUT during follow-up (20.50±8.18 minutes vs 12.84±5.88 minutes).

A strength of the current study is that we also included an objective measurement of PA by means of the Sensewear armband. This allowed us to additionally capture non-structured or non-intended minutes of moderate to vigorous intensity PA (e.g., climbing a flight of stairs). Interestingly, only AUT significantly increased from pre to post for total daily energy expenditure and objectively measured moderate intensity PA (≥2MET). It seems that the coaching in AUT had an additional positive effect on daily life activity in the short-term. A possible explanation is that the coach in AUT emphasized the importance and benefits of regular PA more than the coaching in STRUC. However, once the positive feedback and reinforcements by the coach disappeared, the level of PA dropped to baseline levels. Therefore, the findings suggest that the presence of a coach is important for older adults in order to persist in PA in the long-term.

As discussed above, ergometer cycling is feasible in the short- and long-term in older adults living in assisted living facilities. However, compared with the control group, no greater improvements were observed in STRUC or AUT on functional performance, muscle strength and fall frequency. Given the broad range in adherence rates within our training groups, we decided to additionally compare adherers (completed at least 80% of exercise sessions during the intervention) with non-adherers. Interestingly, adherers were able to counteract declines in muscle strength compared to non-adherers in the short-term, although this trend did not reach statistical significance (P=.054). This result is in line with Buchner et al. (1997) who found a significant increase in leg strength after 3 months of cycling exercises in older adults (65–85 years). Moreover, adherers increased their step length in the long-term and showed higher scores on the mPPT in the short-term as compared to non-adherers. This is in line with previous research showing the effects of cycle ergometer programs on functional performance in older adults. Denison et al.(2013) (mean age 71 years) did not find an increase in the 3metre walk and chair rise test, but Lee and Cho (2014) found significant improvements in gait (i.e., step time and step length) and balance after an 8-week stationary bicycle program in elderly women (mean age 69.1 years). Although some positive effects were found on balance measurements (i.e., step length and 'turning 360°'), no significant difference on fall frequency was found. An explanation is that falls occur as a result of several factors. Next to extrinsic risk factors (e.g. home and footwear), different person specific risk factors can play an important role: lower extremity weakening, balance and gait, vision, medications and cognitive impairment (Ambrose, Paul, & Hausdorff, 2013).

It appears that ergometer cycling has some effects on functional performance and muscle strength in the short-term but it is not sufficient to increase function in older adults living in assisted living facilities in the long run. A first possible explanation for this lack of training effect is the relatively low intensity of the exercise sessions. The stationary bicycle was set to no resistance, which is probably not sufficient to optimally stimulate the muscular systems. Moreover, because we included an older study population (mean age 82 years), training volume and frequency was lower than in previous studies. A second feature that might have affected the response to exercise was intermittent illness and hospitalization that occurred in some residents. Any improvement would have been quickly reversed by the inactivity of bed rest, causing detraining effects.

We acknowledge that the present study has some limitations. First, there might be a lack of statistical significance due to the wide variation in performances in older adults. A second limitation concerns the drop-out. It remains unclear whether missing data at follow-up has influenced the findings, as participants who dropped out at follow-up were older and more functionally dependent than those who completed follow-up. Third, not all participants had available data for objectively measured activity. To be included in the analyses, participants needed valid Sensewear data (i.e. wearing time of at least 95%) of Sunday and at least three other days.

This study also had some specific strengths. First, to our knowledge, this is the first study investigating the effects of a cycle ergometer intervention in assisted living facilities. Second, the sample was considerably older than in previous cycle ergometer interventions in older adults (Buchner et al., 1997; Denison et al., 2013; Lee & Cho, 2014). Third, the effects on PA were evaluated with both self-reported and objective measures. Only few intervention studies using objective monitoring have been conducted with older adults (Strath, Pfeiffer, & Whitt-Glover, 2012). Moreover, subjectively and objectively measured PA can differ substantially as demonstrated in the present study. Fourth, the intervention was embedded in the existing structures of the assisted living facilities. More specifically, the cycle ergometers were placed in a common area (e.g., cafeteria), and were therefore accessible to all residents.

CONCLUSION

The findings of the present study suggest that a minimal contact cycle ergometer intervention is effective to promote cycle ergometer use in assisted living facilities. Although more structure and assistance during the initial period resulted in higher training volumes, a limited number of contact moments should be favored as it is more feasible in real life settings. Moreover, autonomy-supportive coaching had an additional positive effect on daily life activity in the short-term.

Ergometer cycling seems feasible for older adults living in assisted living facilities. Adherers show better short-term results on functionality and muscle strength, even though improvements are small. Notwithstanding, there is much more potential for improvements. Further research is required to assess the effects of cycle ergometer programs at a higher intensity level.

FUNDING SOURCE AND TRAIL REGISTRATION

This study was conducted under the authority of the Policy Research Centre on Sports, supported by the Flemish Government. The authors declare that they have no conflicts of interest. This study is registered at www.clinicaltrials.gov (No. NCT01748461).

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PART 3

SUMMARY AND GENERAL DISCUSSION

The projects that have been carried out in this doctoral thesis entitled 'Objective assessment and promotion of physical activity (PA) in older adults living in residential care facilities' focused on three interrelated aims: (1) assessment, (2) screening and (3) intervention. The first aim was to investigate the validity of a piezoelectric pedometer and Sensewear Mini (SWMini) in nursing home residents (**CHAPTER 1**, ***Paper 1*** and ***Paper 2***). The second aim was to examine the link between muscle strength and functional performance, and to identify functionally relevant cut-off values for muscle weakness in older adults (**CHAPTER 2**, ***Paper 3***). ***Paper 3*** showed a significant association between muscle strength and functionality and showed that knee extension strength is a better predictor of functional performance than handgrip strength in assisted living facilities. Therefore, the last aim was to examine the short- and long-term effects of a cycle ergometer intervention in assisted living facilities (**CHAPTER 3, *Paper 4***). In this last paper, the SW was used to measure PA.

In the following paragraphs, the main findings of the four research papers will be summarized. Practical implications and suggestions for further research will be pointed out for each chapter.

1. SUMMARY

1.1. Assessment of physical activity in institutionalized older adults

Paper 1 focused on the accuracy of a hip-worn and ankle-worn piezoelectric pedometer New Lifestyles 2000 and the arm-mounted multisensor SWMini in measuring steps in institutionalized older adults. Participants underwent a standardized protocol in which they performed three different tasks, representative of some daily life activities. The final study sample consisted of 14 male and 54 female residents, and mean age was 85.8±5.6 years. Actual steps were tallied with a hand counter. The results revealed that the multisensor and hip- and ankle-worn pedometer significantly underestimated step counts, although measurement accuracy was higher when the pedometer was worn at the ankle. A possible explanation is that a vertical wearing position is more easily maintained at the ankle. Moreover, movements at the ankle are more obvious in comparison with the hip as there is a decrease in step length and step height in the old and old-old (Touhy & Jett, 2012). Pedometer accuracy improved as walking speed increased. A possible explanation is the shuffling gait pattern and gait impairments, which are often observed in slow walking older adults. The ankle-worn piezoelectric pedometer proved to be acceptably accurate (percent error scores within ±5%) for quantifying steps at walking speeds of 2.35 km/h or above. In ***Paper 1***, the SWMini significantly underestimated step counts in older adults. A possible explanation for the high percent error is that the device is worn around the upper arm, which is not an ideal wearing position, as older adults have a diminished arm swing (Touhy & Jett, 2012). Next to step counts, energy expenditure (EE) is a common outcome when assessing PA in daily life. Therefore, ***Paper 2*** focused on the validity of the SWMini to measure EE in the old and old-old during rest (i.e., sitting quietly) and during the performance of daily life activities (i.e., walking, sitting/rising/walking, moving objects). Out of the 68 nursing home residents that were included in ***Paper 1***, sixty residents (mean age = 85.5±5.5 years) had valid data for the portable gas analyzer Oxycon Mobile, which estimated the criterion EE. The results showed that EE estimated by the SWMini demonstrated good agreement with the criterion EE (ICC=0.75), although the SWMini underestimated EE (overall percent error score of 14.1±7.9%). Age was determined as a key factor of accuracy and explained 12% of the variance in total percent error. However, the analyses in ***Paper 2*** revealed that the SWMini found significant differences in EE during sitting periods and activity tasks (mean difference=58.2%±7.4%). Therefore, the SWMini can be used in studies describing sedentary behavior in the old and old-old considering that the device detects interruptions in sedentary time. This information is valuable as recent studies showed that, independent of the level of moderate to vigorous intensity PA, sedentary behavior is an important health risk factor (Tremblay et al., 2010). Evidence suggests that the interaction between physically active behavior and sedentary behavior provides different information than the assessment of one parameter alone. For example, an older adult can accumulate total sedentary time from a small number of long sedentary bouts or from a greater number of short sedentary bouts (Chastin & Granat, 2010).

PRACTICAL IMPLICATIONS

The SWMini and hip-worn piezoelectric pedometer are insufficiently accurate for quantifying steps in the old and old-old. Researchers and practitioners should take into account walking speed when selecting a piezoelectric pedometer for (institutionalized) older adults. Moreover, the SWMini is of limited value for quantifying EE in nursing home residents, but it is a suitable device for researchers interested in patterns of PA and sedentary behavior. It can be used for screening (e.g., quantifying sitting time) and for evaluating interventions to reduce sedentary time in the old and old-old.

FURTHER RESEARCH

- Further research is needed to develop accurate pedometers for (institutionalized) older adults with very slow walking gaits (<2.35 km/h).
- The SW uses activity-specific algorithms to convert movement and physiological data into estimates of EE. It remains a problem to evaluate the validity of those algorithms because they are proprietary to the manufacturer ('**black box**'). ***Paper 2*** showed that age significantly reduces the accuracy of the SWMini, suggesting that accurate age-specific algorithms should be developed. Moreover, activities such as upper limb activities or stationary bicycling were not evaluated in ***Paper 2***. Although walking is the main activity of nursing home residents, additional studies are needed before conclusions can be made about the overall agreement of the multisensor in the old and old-old.

- It would be interesting to analyze the patterns of PA and sedentary behavior in the old and old-old using the multisensor. These patterns can be useful for future studies to identify intervention targets and opportunities. For example, patterns can provide information on when older adults are (in)active during the day and when there are some opportunities to promote PA.

1.2. Muscle strength as a predictor of functional impairment

Paper 3 examined whether knee extension and handgrip strength, measured using two field tests are good predictors of functional performance among older adults (≥60 years). In total, 770 community-dwelling older adults, 104 older adults living in assisted living facilities and 73 nursing home residents were included to cover a broad range of strength performance and functionality levels. Results revealed that both handgrip (r = 0.35–0.59) and knee extension strength (r = 0.50–0.63) were positively correlated with functional performance in all settings. In the community and nursing homes, both strength variables equally contributed to functional performance. In assisted living facilities only, knee extension strength proved to be a better predictor of functional performance ($R^2_{6MWD} = 0.39$ and $R^2_{mPPT} = 0.35$) than handgrip strength ($R^2_{6MWD} = 0.15$ and $R^2_{mPPT} = 0.12$). Cut-off values for men and women respectively, were set at 0.40 and 0.31 kg per kg body weight (BW) for lower body strength and at 0.43 and 0.31 kg per kg BW for upper body strength.

PRACTICAL IMPLICATIONS

Early identification of high risk individuals may create opportunities for developing and implementing strategies to counteract disability. The abovementioned cut-off values should be used in clinical practice to detect and double check older adults at risk for muscle weakness, using simple field tests. In addition to screening purposes, both field tests, and especially the static knee extension strength test, might also be used to evaluate age- and training-related adaptations in large-scale studies among older adults.

FURTHER RESEARCH

Only static strength measurements were included in ***Paper 3***. Previous studies already showed that dynamic strength, power and speed of movement of the knee extensors might be more important for functional performance in older adults (Van Roie et al., 2011). Moreover, static contractions are rarely needed for the performance of daily life activities. Therefore, standardized and easy-to-use measurements should be developed for dynamic strength and power evaluations in older adults.

1.3. Cycle ergometer intervention in assisted living facilities

Individuals living in assisted living facilities are often close to or just entering the early stages of functional limitations and are therefore an important target population for intervention purposes. These early stages of functional limitations might be caused by declines in knee extension strength, which have been shown to exceed declines in handgrip strength. Moreover, the results in ***Paper 3*** showed that knee extension strength was clearly more predictive than handgrip strength in residents living in assisted living facilities. Ergometer cycling involves low impact movement and trains the cardio-respiratory system as well as lower body muscles. Therefore, the purpose of ***Paper 4*** was to evaluate the short- and long-term effectiveness of a 10-week cycle ergometer intervention in older adults living in an assisted living facility. Ninety-five residents participated and mean age was 82.1±5.9 years. Participants were assigned to one of the three following conditions: (1) a structured coaching program (STRUC), consisting of three weekly supervised sessions on a cycle ergometer, (2) an autonomy-supportive coaching program (AUT) based on the Self-Determination Theory (SDT), consisting of an individualized cycle ergometer program with minimal coaching contact, or (3) a control group. Especially the autonomy-component considerably differed between both interventions groups as participants in AUT had to complete the program on their own. Results showed that older adults can be motivated by a PA coach to start exercising on a cycle ergometer. However, adherence to the 10-week program and training volume were higher in STRUC compared with AUT. After the intervention period adherence rates were similar in both intervention groups, although training volume was still higher in STRUC. It seems that stimulating autonomy in this age group does not result in higher long-term adherence rates. Self-reported moderate intensity PA increased more from pre to post in both intervention groups in comparison with the control group. In addition, only AUT showed short-term gains in daily EE and objective measured moderate intensity activity, but these effects disappeared at follow-up. At last, adherers (≥80% of training sessions from pre to post) showed a greater increase from pre to post for functionality and muscle strength in comparison with non-adherers, even though improvements are small.

PRACTICAL IMPLICATIONS

As ergometer cycling was found to be feasible in this functionally limited age-group, assisted living facilities can use the specific cycle ergometer training program with different starting levels. Ergometer cycling is relatively simple and when the cycle ergometer is placed in a common area, several residents can use the device, reducing the implementation cost. Although more structure and assistance during the initial training period resulted in higher training volumes, a limited number of contact moments can be favored as it is more feasible in real life settings (i.e., lower implementation cost).

FURTHER RESEARCH

Ergometer cycling has some effects on functional performance and muscle strength in the short-term, but it seems not sufficient to increase function in older adults in the long run. However, there is much potential for improvements. Further research is required to assess the effects of cycle ergometer programs at a higher intensity level.

2. GENERAL DISCUSSION

This doctoral thesis offers important information regarding PA and physical fitness in the older population, especially in the old and old-old. Researchers and practitioners can consider this information for further recommendations and decisions. However, some points of discussion need to be raised. The discussion will focus first on aspects related to the study samples and the recruitment of participants in the different studies. Second, some discussion points related to the use of subjective measures of PA and the validated objective measures of PA (***Paper 1*** and ***Paper 2***) in the old and old-old will be put forward. Third, the use of the specific cut-off values for muscle strength (***Paper 3***) in older adults (and our study participants) will be described. At last, the efficacy and effectiveness of the cycle ergometer intervention in assisted living facilities described in ***Paper 4*** will be discussed. Suggestions for further research and practical implications will be pointed out.

2.1. Methodological considerations

2.1.1. Old age of study participants

An overall *strength of the present doctoral thesis* is the old age of the study participants. It is important to include older adults in public health studies and PA interventions because of the following reasons. (1) Populations around the world are aging rapidly. Moreover, the fastest growing segments are the old and old-old (Christensen et al., 2009). (2) The older population is at the highest risk for chronic diseases and losses in function. This will eventually lead to a loss of independence and increased health care costs. Therefore, ‘active aging’ has become an important issue in public health research.

The study sample for the validation studies was larger and considerably older (mean age=85 years) than previous validation studies in older adults (Bergman et al., 2008; Cavalheri et al., 2011; Grant et al., 2008; Hermann et al., 2014; Hill et al., 2010; Marsh et al., 2007; Patel et al., 2007; Van Remoortel et al., 2012). The strength of ***Paper 3*** was that three major living options in older adults were included: community-dwelling older adults, older adults living in assisted living facilities and nursing home residents. In ***Paper 4***, the participants were residents of assisted living facilities, with a mean age of 82 years old. The sample was considerably older than in previous cycle ergometer interventions in older adults (Buchner et al., 1997; Denison et al., 2013; Lee & Cho, 2014).

It should be noted that there are internationally accepted definitions of old age (i.e., 'young old' = 65-74 years, the 'old' = 75-84 years, the 'old-old'= 85-99 years) (Taylor & Johnson, 2008). However, there is no general consensus when a person becomes 'old'. The '**calendar or chronological age'** (i.e., passage of time from birth in years) is not always a synonym of the '**biological age**' (i.e., processes within the body that lead to disability or diseases) or '**functional age**' (i.e., one's functional fitness in comparison with others of the same age). For example, an 80-year-old woman can have an aerobic endurance of a woman of 60 years old (Jones & Rose, 2005). In a study by Prevc and Doupona (2009), subjective age ('**felt age**') was also 5.5 years less than the chronological age. In addition, because of increased life expectancy, increased medical knowledge and increased quality of life, chronological age categories can change over time. In the future, 75-84 years can become the age-category 'young-old' ("60 is the new 40") (Touhy & Jett, 2012).
Because of the abovementioned aspects, we did not select participants on the basis of age ('chronological age') (***Papers 1, 2*** and ***4***). Only those older adults living in a specific housing facility (i.e., assisted living facility or nursing home) were included, as housing depends on the older adult's specific needs and personal requirements (next to preferences) ('functional age'). For example, in assisted living facilities, residents are often close to or just entering the early stage of physical impairment. These facilities combine independence with personalized supportive care to meet the needs of older adults in daily life activities.

2.1.2. Proportion of male and female participants

When we take a closer look to the proportion of male and female participants in the present doctoral thesis, more women than men participated in the studies. In **CHAPTER 1**, the validation study in nursing homes, the study population consisted of 79.4% women. In the intervention study (**CHAPTER 3**), 76.8% of the participants living in assisted living facilities were women. **CHAPTER 2** included those participants of **CHAPTER 1** and **3** and participants of 3 other studies. The community-dwelling older adults, older adults living in assisted living facilities and nursing home residents consisted of 66.9%, 71.2% and 76.0% female participants, respectively. These numbers are not surprising, as the majority of older persons are women. The **sex-ratio** (i.e., the number of men per 100 women) is lower the older the age group (United Nations - Department of Economic and Social Affairs - Population Division, 2012). A ratio greater than 100 indicates more men than women in a given age group. In Belgium, the sex ratio for older adults ≥60 years is 80 men/100 women (≈ corresponding with 56% women). For older adults 80 years or older, the sex ratio is 53 men/100 women (≈ corresponding with 65% women). The discrepancy between men and women can be largely explained by the higher life expectancy of women. Current life expectancy of European men and women at birth is 77.5 and 83.1 years, respectively (Eurostat, 2014). However, it should be noted that percent female participants is slightly higher in our studies (67% - 79%) in comparison with the overall percentage of women in the older population in Belgium (56% - 65%). It remains unclear whether or not men were underrepresented because they could not participate because of physical or mental problems or because they were less interested.

Although women are overrepresented in the older categories of the population (United Nations - Department of Economic and Social Affairs - Population Division, 2012), it remains important to take the gender aspect into account as men and women respond differently to aging. Rates, trends, and specific types of different disabling conditions (e.g., musculoskeletal problems) differ between women and men (Murtagh & Hubert, 2004; World Health Organization, 2003).

In ***Paper 1***, no significant differences were found between men and women for step count accuracy of the piezoelectric pedometer worn at the ankle or hip or the SWMini. The SWMini includes a triaxial accelerometer along with physiological sensors. The device estimates EE minute-by-minute through automatically applied algorithms, using information regarding accelerometer and the physiological sensors, and participants' demographic characteristics (i.e., sex, age, height, weight, smoking habit, and handedness). ***Paper 2*** revealed significant differences between men and women for EE during daily life activities. During sitting periods and activity tasks, men showed higher levels of EE than women (sitting, 1.53±0.22 vs 1.23±0.21 kcal/min; activity tasks, 4.02±0.89 vs 2.87±0.66 kcal/min). However, no significant correlations were observed between percent error of the SWMini (compared with indirect calorimetry) and sex. We did find higher absolute percent error scores of the SWMini in women, although the difference was not significant (15.22±8.46% in women compared with 11.13±5.69% in men). In ***Paper 3***, sex-specific cut-off values for grip strength and knee extension strength were obtained, as strength significantly differs between men and women (Janssen et al., 2000; Martien et al., 2014). The cut-off value for knee extension strength was set at 0.40 kg/kg BW for men and at 0.31 40 kg/kg BW for women. For grip strength, the cut-off value was set at 0.43 40 kg/kg BW for men and 0.31 40 kg/kg BW for women. Because of the rather small study sample in the intervention study (***Paper 4***) there were not enough men in the three intervention conditions to perform separate analyses for men and women. However, in the future, the differences between men and women completing a cycle ergometer program should be investigated. This might be important as Denison et al. (2013) showed significant differences between men and women in the timed up and go test-performance after a 12-week cycle ergometer intervention in older adults.

FURTHER RESEARCH

Future intervention studies using a cycle ergometer in the old and old-old should include separate analyses for men and women, as they might respond differently to cycle ergometer exercise.

2.1.3. Recruitment of older participants

Participation in health-oriented and PA programs mostly relies on voluntarism. Inactive, chronically ill and mobility restricted older adults are difficult to reach for PA interventions (the '**hard to reach**'). In a study by de Souto Barreto et al. (2013) '**participation bias**' was related to volunteering for an exercise study. Older adults who volunteered to participate were younger, reported higher volumes of PA and showed less physical function decline than non-volunteers. Moreover, non-volunteers had a worse self-reported health and suffered more frequently from chronic pain (de Souto Barreto P., Ferrandez, & Saliba-Serre, 2013). Therefore, active recruitment procedures that approach the entire population should be applied. A *strength of the present doctoral thesis* is that participants were personally contacted to participate in the studies of **CHAPTER 1** and **3** by the use of a door-to-door strategy.

2.1.3.1. Door-to-door strategy

The nursing home and assisted living residents in **CHAPTER 1** and **3** were personally contacted (face-to-face) and asked to participate in the validation or intervention study (="**direct method**"). Participants did not have to respond to an advertisement or newspaper (="**indirect method**"). Therefore, participants that would not participate spontaneously could be convinced to participate, or at least to try the first test session. Although this 'door-to-door' approach requires a higher implementation cost, it heightens the probability that the less motivated and mobility restricted residents can be convinced to participate.

Because of the direct recruitment strategy, a strength of the present dissertation was the representativeness of the older population. We tried to include a wide range of older adults, including functionally limited and chronically ill older adults. In nursing homes physical dependence is often measured by the Katz-index. Residents can be ranked into five categories according to their ability to perform activities of daily living (i.e., O, A, B, C and Cd). "O" stands for complete independence, whereas "Cd" stands for complete dependence (Katz et al., 1963). In **CHAPTER 1**, 14.7% of the participants scored "O" on the Katz-score, but also 19.1% scored "Cd". In **CHAPTER 3**, the modified Physical Performance Test (mPPT) was used as a measure of functionality related to daily activities. Participants can be grouped according to their score on the mPPT as not frail (32–36 points), mildly frail (25–31 points), or moderately frail (17–24 points). An mPPT-score below 17 indicates that the individual is unlikely to be able to function in the community (Brown et al., 2000). In ***Paper 4***, 31.6% of the participants scored ≥32 on the mPPT, 34.7% scored lower than 25 points on the mPPT and even 8.4% scored lower than 17 points.

2.1.3.2. The role of the general practitioner in the recruitment of older adults

The abovementioned door-to-door approach is suitable for use in assisted living facilities and nursing homes as residents live close together (i.e., time-efficiency). However, it should be noted that it still takes time to convince older adults – and especially the old and old-old – to participate in a PA intervention. The general practitioner can play an important role in the recruitment of older adults (=”**third party**”). General practitioners have regular face-to-face contact with older adults and are perceived as the most trusted source of PA information. In addition, they often have (the only) trusting long-lasting relationships with older adults. One intrapersonal barrier in older adults to participate in PA is “professional advice”, especially when a health care provider advised not to engage in PA (see also 5.3. of the Introduction) (Baert et al., 2011). Moreover, those more likely to trust their physician were older adults, those with chronic disease, and the insufficiently active (Schofield, Croteau, & McLean, 2005). However, in a study by Hirvensalo et al. (2005), a substantial proportion of older people recalled that they get negative advice, no advice, or contradicting advice by health care professionals about physical exercises. No PA advice was most common among people who were older and not involved in PA, who had fewer chronic conditions and reported no mobility limitation. General practitioners should be aware of the fact that older adults can benefit from PA, also those older adults having heart conditions, mobility problems or musculoskeletal diseases. This is important as the general practitioner often has to give his/her for permission for participation in PA measurements or a PA intervention. Also in **CHAPTER 1** and **CHAPTER 3** of the present doctoral thesis the practitioner had to screen participants for several exclusion criteria (e.g., cardiovascular disorders, dementia). Residents could only participate if permission from the general practitioner was obtained.

PRACTICAL IMPLEMENTATION

The general practitioners should be aware of the positive effects of PA in the old and old-old and should be informed about the possibilities to promote PA in the older population. Moreover, specific attention should be paid to the advice by the general practitioner, as this can discourage older adults from being physically active.

2.2. Physical activity assessment in the old and old-old

In the following paragraphs, the use of the objective PA measures described in **CHAPTER 1** (i.e., piezoelectric pedometer and SWMini) and the use of a PA questionnaire in older adults will be discussed. The differences between the measures will also be considered.

2.2.1. *Use of a piezoelectric pedometer in the old and old-old*

Paper 1 revealed that the threshold value for accurate step counting (e.g., providing percent error scores within ±5%) was 2.35 km/h for an ankle-worn piezoelectric pedometer. Mean walking speed in our studies was 2.0 km/h for nursing home residents and 3.0 km/h for residents living in assisted living facilities. The ankle-worn piezoelectric pedometer would be applicable for 30% of the nursing home residents, namely for those residents whose walking speed exceeds the threshold value of 2.35 km/h. In the assisted living facilities, 24.2% could not use the piezoelectric pedometer accurately. Consequently, the pedometer was not included to measure changes in PA in ***Paper 4***. Moreover, the main focus of ***Paper 4*** was ergometer cycling. Increases in PA would be more apparent using measurements that capture minutes of moderate intensity PA or EE, as pedometers only record steps and do not reflect frequency and intensity of movement over time. Therefore, in ***Paper 4*** the SW was used to measure EE and minutes of light, moderate and vigorous intensity PA.

2.2.2. *Use of the multisensor Sensewear in the old and old-old*

In ***Paper 4***, the SW was used to detect changes in total EE and PA behavior after a cycle ergometer intervention in assisted living facilities. The SW combines accelerometry with noninvasive physiological sensors that measure conductivity, skin temperature, and heat dissipating from the body. It should be noted that the use of the SW is not ideal in the old and old-old as ***Paper 2*** showed a significant underestimation of EE during sitting periods and daily life activities (overall absolute percent error = 14.1±7.9%). Despite the significant underestimation, we chose to include the SW because of the two following reasons:

(1) First, we wanted to include an overall measure of PA. The SW was worn for 24 hours on 7 consecutive days (except during bathing activities). This allowed us to capture non-structured or non-intended minutes of PA, which cannot be captured by self-reported PA measures. Moreover, only few intervention studies using objective monitoring have been conducted with older adults (Strath, Pfeiffer, & Whitt-Glover, 2012).

(2) Second, there are some differences between nursing home residents (the study population for the validation study) and assisted living residents (the study population for the intervention study) that may have an impact on the validity of the SW. For example, walking speed (3.02 km/h in comparison with 2.0 km/h in nursing home residents) and step length (50.6 cm in comparison with 36.1 cm in nursing home residents) were higher in assisted living residents, and may positively influence the accuracy of the accelerometer sensor. Moreover, it is possible that skin and body composition slightly differ between nursing home residents and assisted living residents. These differences may have an impact on the physiological sensors of the SW. In addition, ***Paper 2*** only validated the SW during a 30-minute protocol. It is possible that percent error scores are different when the device is validated over a 24h-period.

2.2.2.1. Sensewear Mini versus Sensewear Pro

In ***Paper 4***, both the SWMini and SWPro were used. The SWMini is a smaller and thinner version of the SWPro and the SWMini uses a triaxial instead of a biaxial accelerometer. It should be noted that some studies showed significant differences between SWMini and SWPro. Johannsen et al. (2010) showed better agreement for the SWMini compared with the older model SWPro in a sample of healthy adults. Although differences were found in accuracy, both SWMini and SWPro were included in ***Paper 4*** due to practical reasons and because some participants had a cardiac pacemaker (10 out of 95 residents). Participants were randomly given a SWPro or SWMini, except those participants that had a cardiac pacemaker. To avoid interference with the pacemaker as much as possible, participants were given a SWPro when the cardiac pacemaker was inserted in the left subclavicular region, as the SWPro is worn over the right triceps. Participants having a pacemaker inserted in the right subclavicular region were given a SWMini, worn over the left triceps.

Because of the differences between SWMini and SWPro, and because of the significant underestimation of EE by the SWMini (***Paper 2***), participants in the intervention study were given the **same SW-model during pre, post and follow-up measurements**. Moreover, data for SWMini and SWPro were processed using the **same software version** (7.0), as previous studies revealed significant differences between software versions. Smith et al. (2012) showed a significantly smaller error for the newer version 5.2 than the older version 2.2 algorithm in a sample of pregnant women, whereas Mackey et al. (2011) suggested that version 5.1 algorithms are more accurate than version 6.1 algorithms for older adults.

2.2.2.2. Use of metabolic equivalents in older adults

For the validation of the SWMini in ***Paper 2***, we did not use metabolic equivalents (METs) to quantify the energy cost estimated by the portable gas analyzer Oxycon Mobile, but EE (expressed in kcal/min). One MET is considered a resting metabolic rate (RMR) obtained during quiet sitting (Ainsworth et al., 1993). Intensities of activities can be classified as multiples of 1 MET. More specifically, MET intensity reflects the associated metabolic rate divided by the standard RMR of **3.5mlO_2/kg/min** (=1MET). MET-values associated with different activities can be found in the compendium of Ainsworth. However, it should be noted that the compendium was not developed to determine the exact energy cost, instead it was developed to provide an activity classification that standardizes the MET-values of physical activities (Ainsworth et al., 1993). A caution supplied by Ainsworth et al. (1993) is that MET values are representative for adults without conditions altering their metabolic efficiency. The compendium does not take into account individual differences that may alter the energy cost of movement. However, older adults have reduced movement efficiency because a higher energy cost is needed to accomplish the same workload as in young adults. Therefore, METs should be adjusted upward. More specifically, recent studies have questioned the accuracy of 3.5mlO_2/min/kg to define 1 MET in older adults because RMR decreases per decade (Luhrmann, Edelmann-Schafer, & Neuhauser-Berthold, 2010). Byrne et al. (2005) stated that the average VO_2 corresponding with sitting quietly (i.e., rest) is lower (i.e., 2.6±0.4 mlO_2/kg/min) than the commonly accepted 1 MET values of 3.5 ml/O_2/kg/min. As older adults have a lower RMR, the METs needed to accomplish a same amount of work have to be higher in comparison with younger adults. In a study by Hall et al. (2013) standard METs were 71% lower than the measured METs across all walking activities in older adults. Because of the abovementioned aspects, EE instead of MET-values was used to validate the SWMini against indirect calorimetry (***Paper 2***).

On the other hand, for the data collected by the SW in ***Paper 4***, MET-values were applied for the classification of exercise intensity. The MET-values were used to quantify minutes of light and moderate intensity PA (expressed in min/week). However, based on the abovementioned discussion points concerning the use of METS in older adults no ‘standard values’ for light (≥1.5MET <3 MET) and moderate intensity (≥3MET <6 MET) PA were used (Haskell et al., 2007). A different definition of aerobic intensity is appropriate for the old and old-old, as fitness levels can be low. Performing 3 to 6 METS, defined as moderate intensity in adults, requires mostly vigorous effort or is even impossible for older adults. According to commonly-applied PA recommendations by the American College of Sports Medicine (ACSM) for older adults >80y, the following MET cut-points were used to define light and moderate intensity PA in residents living in assisted living facilities (***Paper 4***): **≥1MET <2MET for light intensity PA and ≥2MET for moderate intensity PA** (Pollock et al., 1998).

Furthermore, it should be noted that in ***Paper 4***, all minutes of light (>1MET <2MET) and moderate (≥2MET) intensity PA were included in the analyses. Nevertheless, PA guidelines propose that older adults should attain 30 minutes of moderate to vigorous intensity PA per day in **bouts of at least 10 minutes** to achieve beneficial health effects. In a study by van Remoortel et al. (2013) moderate to vigorous intensity PA analyzed in bouts (i.e., minutes of moderate to vigorous intensity PA performed in bouts of >10 minutes continuous activity) was 2 to 4 times lower in healthy subjects (62±6 years) and even 3 to 12 times lower in COPD patients when compared with total minutes of moderate to vigorous intensity PA (= non-bouts analyses). However, in ***Paper 4*** we did not only include activity bouts of at least 10 minutes because some participants only exercised 3+3 or 4+4 minutes on the cycle ergometer. Moreover, a large proportion of the old and old-old cannot perform long bouts of PA and they often have to interrupt PA to rest. In addition, in our specific cycle ergometer training program, we included some minutes of rest (i.e., 3-5 minutes) between the cycle ergometer exercise bouts (see ***Paper 4***).

2.2.3. Difference between objectively and subjectively measured physical activity

In ***Paper 4*** PA was measured in an objective way, but also in a subjective way, using a modified version of the **Physical Activity Scale for Elderly** (PASE) (Washburn et al., 1993). Participants were asked to recall the number of days per week and the number of hours per day they had spent in light (e.g., slow walking [during leisure time and for transportation], petanque, exercises at home), moderate (e.g., cycling, swimming, gardening) and vigorous (e.g., running) intensity PA in a typical week during the past month. Even though self-reported measures of PA have a number of limitations (i.e., interpretation of light, moderate and vigorous PA; social desirability; poor recall ability – see 4.1. in the Introduction) (Sallis & Saelens, 2000; Tudor-Locke & Myers, 2001), we chose to additionally include subjective measures of PA in ***Paper 4***. These measures were included because they are low cost and because they provide information on type and context of the PA (i.e., walking during leisure time or for transportation) (Sallis & Saelens, 2000). It should be noted that, to overcome some of the abovementioned limitations of self-reported PA, the PASE-questionnaire was administered by an interviewer. The interviewer discussed a typical week during the past month with the residents. All physical activities were written down and afterwards, the interviewer clustered the activities in light, moderate and vigorous intensity PA and calculated total minutes per week.

It should be noted that subjectively and objectively measured PA can differ substantially (Colbert et al., 2011), which was also demonstrated in ***Paper 4***. Total light and moderate intensity self-reported PA in assisted living residents was 276.28±353.36 min/week and 8.16±39.59 min/week, respectively. Total light (>1MET <2MET) and moderate (≥2MET) intensity objectively measured PA (using the SW) was 1329.66±812.43 min/week and 1012.53±616.26 min/week, respectively. The main reason for the large discrepancy between the two measurements is that PA measured with the questionnaire focuses on physical exercise. PA is not the same as exercise. Exercise is planned and structured with the explicit intention to enhance physical fitness, and therefore constitutes only a subcategory of PA (Caspersen, Powell, & Christenson, 1985). When using the SW, overall PA is measured. It includes non-intended and non-structured forms of PA (e.g., climbing a flight of stairs, doing the laundry, making the bed, making dinner…), which are difficult to capture using self-reported measurements (Tudor-Locke & Myers, 2001). As walking is the most important activity in this older population, it is important to use monitors than can capture these unstructured and intermitted forms of PA.

PRACTICAL IMPLEMENTATION

Researchers should be careful when using subjectively or objectively measured PA for screening, goal setting and program evaluation, as it seems that that both measurements capture different aspects of PA.

2.3. Screening for functional limitations in the older population

To our knowledge, ***Paper 3*** of the present manuscript was the first study to identify functionally relevant cut-points for knee extension strength in older adults using a simple field test. Cut-off values for knee extension muscle weakness for men and women were set at 0.40 kg/kg BW and 0.31 kg/kg BW, respectively. In residents living in assisted living facilities (***Paper 4***) mean values for knee extension strength were 0.37 kg/kg BW for men and 0.28 kg/kg BW for women. In total, 52.4% of the male assisted living residents and 63.6% of the female assisted living residents had knee extension strength values lower than the cut-off values determined in ***Paper 3***. This means that more than half of the participants can be considered to have functionally relevant muscle weakness. This is not surprising considering that older adults move to assisted living facilities when they need some help during daily life activities. Assisted living combines independence with personalized supportive care. Moreover, also Giuliani et al. (2008) stated that assisted living residents are often close to or just entering the early stage of physical impairments. Strength measures were also conducted in the nursing home residents (***Paper 1*** and ***Paper 2***). Mean values for knee extension strength were 0.26 kg/kg BW for men and 0.21 kg/kg BW for women. In total, 92.9% of the male nursing home residents and 92.2% of the female nursing home residents have knee extension strengths lower than the presented cut-off values.

It should be noted that cut-points should not always be seen as absolute cut-points, but rather as alarm signals. Moreover, one should combine the cut-point for handgrip (0.43 kg/kg BW for men and 0.31 kg/kg BW for women) and knee extension strength. This "**double check**", will increase sensitivity and misclassified subjects will benefit from a second assessment. The combination of both strength values might aid in the identification of older adults with the highest need for intervention, also suggested by Chan et al. (2014).

Some methodological shortcomings concerning ***Paper 3*** should be mentioned here:
1) The design was cross-sectional, as strength and functional performance were measured at the same time. Therefore, no causal relationships can be determined. For example, it seems likely that older adults who cannot perform many daily life activities will have more declines in muscle strength. However, Hicks et al. (2012) and Rantanen et al. (1999; 2001) already showed that muscle weakness is likely to cause functional performance.
2) Different studies were included to increase both the study sample as well as the heterogeneity of the study sample (i.e., a wide range in upper and lower body muscle strength and functional performance) (Martien et al., 2014; Pelssers et al., 2013; Van Hoecke et al., 2014; Van Roie et al., 2013). Exclusion and inclusion criteria were somewhat different as the main purpose of the studies differed. On the

other hand, all five studies were performed by investigators of the same research group. Therefore, tests were conducted using the same standard procedures.

3) In ***Paper 3***, functional performance and muscle strength were assessed using objective measures, in the form of performance-based tests (i.e., 6MWT, mPPT, strength dynamometer). However, in a study by Kempen et al. (1996) the association between self-reported (e.g., 'Are you able to carry an object weighting 5 kg, for instance a shopping bag?'; 'Are you able to walk 400m without stopping?') and performance-based measures (e.g., shuttle walk test, sit-and-reach test, grip strength) of physical limitations was only moderate (≥57 years). It is possible that performance-based measures do not take into account adaptations made in an older adult's everyday living situation (e.g., compensatory mechanisms like change in footwear, avoid walking on rough, uneven surfaces…). Self-reported and 'objective' measures of physical limitations can yield different kinds of information and seem to complement each other (Kempen et al., 1996). Therefore, it would have been beneficial to additionally include self-reported measures of physical functioning.

2.4. Ergometer cycling in older adults

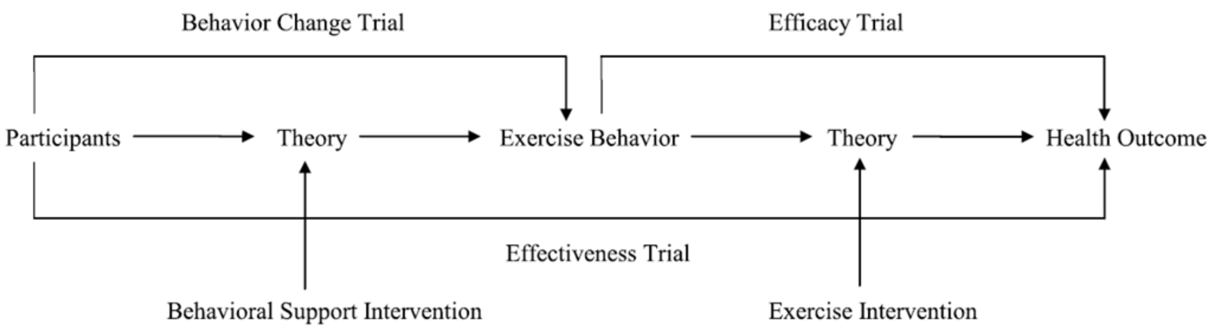
Data gathered during the intervention study revealed that the management of assisted living facilities indicated that PA promotion is not a priority of the facility. Most organized activities have a social goal (i.e., opportunities to be socially connected with other residents) (Hanson et al., 2014) and only few facilities organized active recreational activities (Hanson et al., 2014) (data not published or included in ***Paper 4***). Moreover, in a recent study in assisted living communities, residents indicated a lack of exercise space. They wished for individualized home exercise programs and supervised exercise sessions (Phillips & Flesner, 2013). However, in literature, only few intervention studies focused on the effects of PA in assisted living facilities (van der Bij, Laurant, & Wensing, 2002). Therefore, the purpose of ***Paper 4*** was to evaluate the effects of a 10-week cycle ergometer intervention in older adults living in assisted living facilities. Moreover, we tried to develop an accessible program that can be implemented on a large scale. A specific strength of the intervention study was the longitudinal design, as both short- and long-term effects ('maintenance') were evaluated.

It is important to focus both on health outcomes and on the cost-effectiveness of an intervention (Sox & Goodman, 2012). Such research is especially valuable within the domain of PA promotion in the wider community (King, Rejeski, & Buchner, 1998). Evaluating programs is important to avoid wasting resources and to improve the public health to the desired level (e.g., the PA recommendations).

Before continuing, I would like to clarify some important concepts related to exercise trials. As suggested by Courneya (2010), exercise trials can be divided into "**health outcome trials**" (i.e., effects of an exercise intervention on health outcomes, for example on muscle strength and functionality) or "**behavior change trials**" (i.e., effects of a behavioral support intervention on the behavior itself, for example on PA behavior). However, one trial can pursue both outcomes (Courneya, 2010). Also in ***Paper 4***, the effects of a cycle ergometer intervention on both health outcomes (i.e., the effects of ergometer cycling on biologic outcomes) and exercise behavior (i.e., the effects of two coaching procedures on PA behavior) were studied. Health outcome trials show a further distinction between "**effectiveness**" and "**efficacy**" (*Figure 1*). Effectiveness determines whether an intervention produces the intended effect under real-world conditions and efficacy determines whether an intervention produces the intended effect under ideal circumstances. More specifically, efficacy focuses on those participants who received the intervention (e.g., the 'adherers' in ***Paper 4***), whereas effectiveness focuses on the population to whom the intervention has been offered (e.g., all assisted living residents [in total 417 residents in ***Paper 4***]) (Courneya, 2010). Most trials, including our intervention study, contain a mix of both elements (Chin A Paw et al., 2006). Therefore, in the following paragraphs, the efficacy and effectiveness of a cycle ergometer intervention in assisted living facilities will be discussed using the principles described in *Figure 1* (Courneya, 2010).

In addition, in our description of the efficacy-effectiveness model (Courneya, 2010), some components of the RE-AIM model will be integrated. The RE-AIM model, defined by Glasgow, Vogt and Boles (1999) is an evaluation framework used in public health interventions. RE-AIM stands for: Reach, Efficacy, Adoption, Implementation, and Maintenance (Glasgow et al., 1999; Glasgow et al., 2004). Not all aspects of the RE-AIM model will be thoroughly discussed as the cycle ergometer programs were only implemented in a research design and not yet in real-life settings (i.e., implementation in assisted living facilities that were not included in the intervention study, coaching by individuals who are not part of a research team).

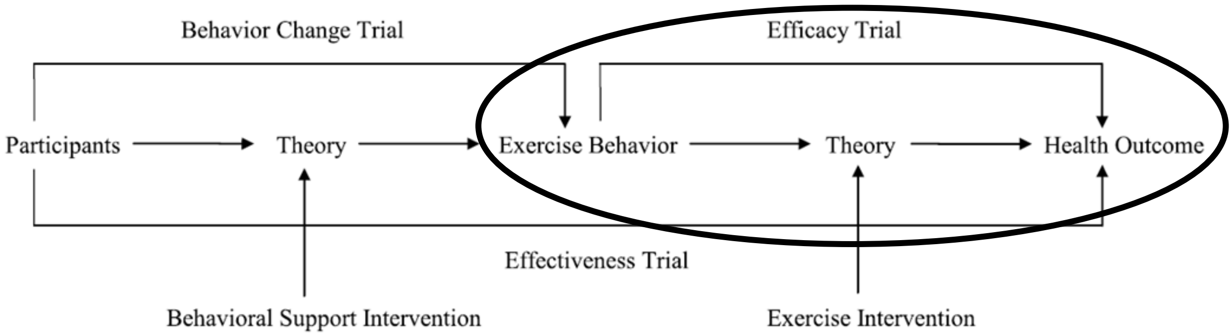
Figure 1. Three types of exercise trials.



Note. Source: Courneya, 2010

2.4.1. Health outcome trial

First, we will take a closer look to the efficacy of ergometer cycling in assisted living residents. ‘Efficacy’ (i.e., success rate) stands for the impact on important outcomes, both positive and negative (Glasgow, Vogt, & Boles, 1999) under ideal conditions.



Note. Source: Courneya, 2010

In ***Paper 4***, adherers (≥80% of cycle ergometer training sessions from pre to post) showed better short-term effects on functionality (i.e., mPPT) and muscle strength in comparison with non-adherers (adherence rate <80% and control group). However, ergometer cycling was not sufficient to increase functionality in the long run (except for step length). This is in agreement with a study of Chin A Paw et al. (2006) that only showed improvements in fitness (reaction time, eye-hand coordination, flexibility) and performance (chair-rise and putting on and off a coat) measures in participants who attended at least 75% of all planned training sessions (twice weekly during 6 months). In this study, training consisted of functional-skills training (to improve muscle strength, speed, endurance, coordination and flexibility) or a combination of resistance and functional-skills training. The authors concluded that less than twice a week exercise training is not enough for functional improvement among older people living in long-term care facilities. However, they stated that it is difficult for older adults to exercise twice weekly because of their limited capacities, ill-health and because an important amount of their time is spent on other activities (e.g., social activities) (Chin A Paw et al., 2006).
Furthermore, increases in our study were rather small. Already defined as clinically significant improvements in physical performance are an increase of walking speed of at least 0.1 m/s or an improvement in the 6-minute walk distance of at least 50 meters (Morley et al., 2011). However, in our study, adherers increased only 0.05 m/s and 13.95±40.56m and from pre to post. Moreover, differences were not significantly different between adherers and non-adherers. Based on the low initial endurance, strength and functionality level of the target group, and the fact that those with the lowest levels can gain the most, it was expected that increases would be larger (even though not all exercise guidelines would be met [e.g., training volume or intensity]). The following paragraph lists some possible explanations for the small increases. However, it should be noted that the older

population is a very heterogeneous group with regard to strength and physical fitness. A wide variability in outcome measurements was found. This influences the size of standard errors and reduces the chance of finding statistical significance.

Possible explanations for the small increases are (1) the low intensity of the exercise sessions, (2) the rather short duration of the intervention period, and (3) the occurrence of illness and hospitalization during the intervention period. We will discuss each of these possible explanations below.

(1) As suggested by ACSM, the frequency and duration (training volume) of an activity is more important than the intensity at the beginning of a program (Mazzeo et al., 1998). Therefore, the stationary bicycle was set to no resistance and no increase in **intensity** was assumed. However, the relatively low intensity was probably not sufficient to optimally stimulate for example the muscular system. Moreover, training volume was rather low as most participants did not cycle for a long time and indicated on the Borg scale that the initial cycle test (i.e., a 6-minute test that was used to determine the initial training volume) was 'somewhat hard' or even 'hard'. Therefore, training programs started with low levels of exercise duration (mean=7.63±2.45 minutes per session). As the program was designed to progress slowly (+2 minutes every week, unless the sessions were perceived as ≥'somewhat hard') in order to prevent relapse and injuries, only few participants (6.6% = 4 out of 61 participants) exercised 30 minutes per session at the end of the 10 weeks. Mean training volume at the end of the 10 weeks was 15.70±7.64 minutes per session and 16.89±8.01 minutes at follow-up. It should be noted that mean training volume in previous studies was larger (20-60 minutes 3x/week), although our study sample was considerably older (Buchner et al., 1997; Denison et al., 2013; Lee & Cho, 2014; Pogliaghi et al., 2006).

(2) The **intervention period** only lasted 10 weeks. The choice for a 10-week intervention was mainly a practical one. The 10-week intervention program was probably too short, especially as ***Paper 4*** assumed that more contact moments with the PA coach are necessary to increase training volume (i.e., training volume was significantly higher in STRUC post-test and at follow-up in comparison with AUT). However, it should be noted that the cycle ergometers were still available in the assisted living facility and a follow-up program was foreseen, but contact moments with the PA coach were no longer scheduled.

(3) A third feature is the occurrence of intermittent **illness and hospitalization**. Kortebein et al. (2008) showed that 10 days of bed rest results in a substantial decrease in lower body muscle strength and power, and aerobic capacity in healthy older adults. Any improvement can be quickly reversed by the inactivity of bed rest. In our study, 18% of the participants (11 out of 61) did not exercise on the cycle ergometer for 1 week or longer (≥3 sessions) from pre to post due to illness or hospitalization (data not published).

Next to the effects on muscle strength and functionality, PA can have positive effects on the cardiopulmonary system, the skeletal system (e.g., bone mineral content), the nervous system and the sensory system and on other health related factors, such as cholesterol and diabetes (Jones & Rose, 2005). Up to now there is a lack of knowledge on the effects of ergometer cycling in older adults on most of the abovementioned factors. Moreover, PA can have positive effects on mental well-being, cognitive impairment, stress, anxiety, depression, and loneliness (Jones & Rose, 2005; World Health Organization, 2010). However, it should be noted that some preliminary analyses showed no significant effects of ergometer cycling on cognitive impairment in ***Paper 4***. The short Mini Mental State Examination (SMMSE - 12 items) was used as a screening test for cognitive impairment (Braekhus et al., 1992). Linear mixed models showed no significant effects on cognitive functioning from pre to post or from pre to follow-up ($P>.05$). It is possible that the intervention period was too short and that the SMMSE is not sensitive enough to detect small changes in cognitive functioning. Moreover, the overall SMMSE-score was relatively high at pre-test (mean = 10.3 ± 1.7) (data not published). Furthermore, analyses did not reveal significant differences in adherence rate between residents having good cognitive functioning (≥9 on the SMMSE) and residents having poor cognitive functioning (<9 on the SMMSE). In addition, no significant changes in the effects of ergometer cycling on PA, functionality and muscle strength were found when cognitive impairment was included as covariate in the mixed models (except for step length) (data not published). This can be partly explained by the fact that the SMMSE-data were negatively skewed (only 11.6% of the residents scored lower than 9 on the 12-item MMSE).

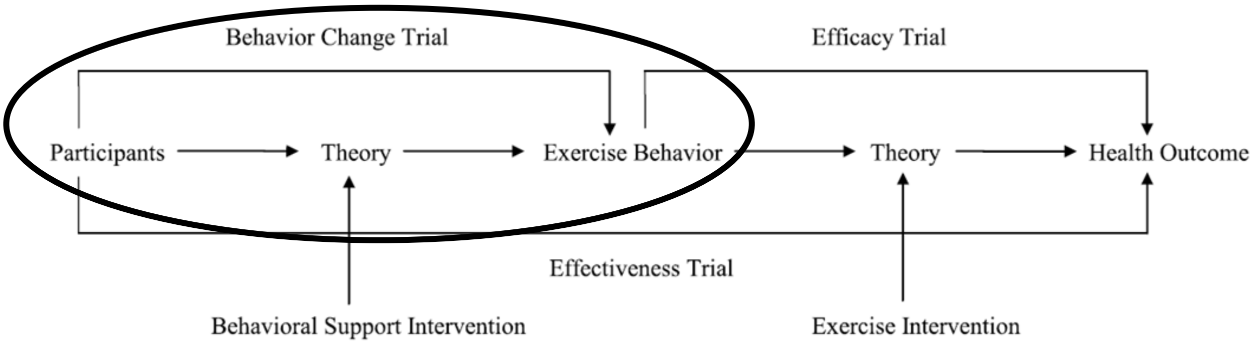
The effects of PA on loneliness are also very relevant for the older population, as nearly one out of ten older people suffers from loneliness, isolation and lack of social interaction. Half of all people ≥75 years live alone and a lot older adults say television is their main company (Hunter, 2012). A PA program in assisted living facilities can offer opportunities to counteract loneliness and social isolation. In ***Paper 4***, participants exercised together in the common area (i.e., cafeteria) and indicated they had more social contact with the other residents than before (data not published).

FURTHER RESEARCH

Future studies should focus on the effects of a cycle ergometer program in assisted living residents on health related physical and psychological factors.

2.4.2. Behavior change trial

As mentioned above, adherence to a cycle ergometer program (≈ ideal circumstances) can have some positive (small) effects on muscle strength and functionality. However, in real life situations, not all participants will reach an adherence rate of 80%. In the following paragraphs, adherence rate will be discussed, comparing two '**behavioral support procedures**' (i.e., the two coaching procedures).



Note. Source: Courneya, 2010

2.4.2.1. Adherence to a cycle ergometer program

As shown in ***Paper 4***, both intervention groups can be motivated by a PA coach to start exercising on a cycle ergometer. Participants in STRUC and AUT exercised on average 2.68 and 2.04 times per week on the cycle ergometer during the 10-week intervention period. After the intervention period ('maintenance'), adherence rate and training frequency significantly decreased in both groups, with no difference between the two conditions. In total, 56.7% of the participants in STRUC and 60.0% of the participants in AUT continued to exercise on the cycle ergometer with an adherence rate of at least 20% (15 trainings sessions over 6 months).

Although the abovementioned data provide important information about the feasibility of a cycle ergometer program in assisted living facilities, it would be interesting to examine when participants dropped out (after 1 week or after 1 month?) and if and when they increased/decreased training frequency and training volume. These patterns of drop out (i.e., time of drop out) can provide important insights. It is possible that many participants dropped out 1 or 2 months after post-test. Future interventions can prevent relapse and schedule for example one more contact moment (or phone call) with the PA coach. A study by Stiggelbout et al. (2005) in community-living individuals showed that timing of dropout can differ substantially between different exercise programs. For example, people who participated in cycling dropped out relatively soon (mainly within 8 weeks), whereas people who participated in walking dropped out later (mainly within weeks 17-26) (Stiggelbout et al., 2005).

FURTHER RESEARCH
Further research should examine the patterns of adherence and drop out to cycle ergometer programs in assisted living residents.

In addition, in ***Paper 4***, no effects of the time of the year were taken into account. Between January and March participants were pre-tested, between March and July post-tested en between September and December follow-up measurements were planned. Seasonal variation can play an important role, as physical activities largely depend on weather conditions in older adults (Mobily et al., 1995). For example, during summertime, residents can prefer walking outdoors over indoor cycling. Stiggelbout et al. (2005) showed that 31% of people (mean age 60.9 years) who dropped out of one type of exercise program switched to another type of exercise. However, this switching behavior was influenced by type of exercise. For example, only few people who dropped out of cycling switched to another type of exercise (Stiggelbout et al., 2005).

2.4.2.2. Self-Determination Theory

Within behavior change, interventions using counseling procedures with a theoretical basis tend to show larger effects than non-theoretically based interventions (Chase, 2014). An underlying theory can help to understand why an intervention was effective or not. The SDT has been postulated as a promising theoretical approach. The theory assumes that a need-supportive environment (supporting the needs for autonomy, relatedness and competence) might be helpful to produce long-term behavior change (Chatzisarantis & Hagger, 2009; Van Hoecke et al., 2014). This is important as older adults often fall back into their inactive lifestyle after an intervention program (Taylor et al., 2004). In ***Paper 4***, two coaching procedures were compared, a structured coaching and a need-supportive coaching program based on the SDT. Especially the autonomy-component differed considerably between both intervention groups as participants in AUT had to complete the program on their own. This autonomy-component might be crucial for the old and old-old, as they often experience a lower sense of personal control (need for autonomy) (Mirowsky, 1995). Moreover, the importance of autonomy ('sense of control') was shown by Langer and Rodin (1976). During their field experiment in nursing homes, the effects of enhanced personal responsibility and choice were examined. Residents in the experimental group were given the freedom to make choices and the responsibility of caring for a plant. Results showed significant improvements on alertness, active participation and a general sense of well-being (happiness) (Langer & Rodin, 1976). In addition, the importance of personal control for exercise motivation is supported by Jette et al. (1998). They found that older adults with a greater sense of control had higher adherence rates to a home-based resistance training program (Jette et al., 1998). Furthermore, it should be noted that nowadays more and more residential care facilities attach importance to the 'sense of control' of their residents.

In the following paragraphs the need-supportive characteristics of both coaching procedures will be discussed. Two questionnaires, completed after the intervention (i.e., post-test) will be used. It should be noted that the results concerning need support and motivation were not included in ***Paper 4*** because of two reasons: First, many participants mentioned difficulties with several items of the questionnaires. Moreover, the questionnaires were not validated in the old and old-old. Second, the questionnaires were interviewer-administrated by the PA coach. It is possible that participants gave socially desirable answers.

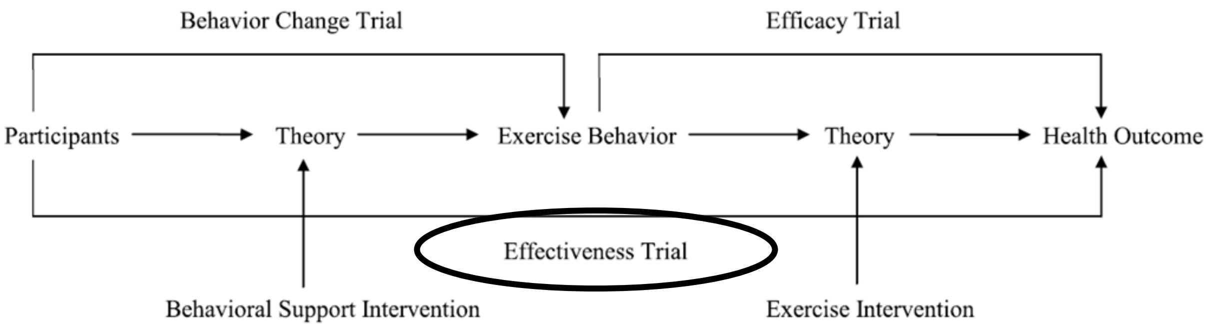
(1) Participants **perceived need-support** of the PA coach was measured using a modified version of the Teacher as Social Context Questionnaire (TASCQ) (Belmont et al., 1988). Examples are ‘my coach listens to my opinion and ideas’ (i.e., autonomy), ‘my coach shows me how to solve a problem’ (i.e., competence), ‘my coach really cares about me’ (i.e., relatedness).
(2) The Basic Psychological Needs in Exercise Scale (BPNES) (Vlachopoulos & Michailidou, 2006) was used to assess the **need-satisfaction** for the need for autonomy, competence and relatedness (by others).

The results of the abovementioned questionnaires revealed that perceived autonomy-support from the PA coach (TASCQ) was higher in STRUC in comparison with AUT. This finding is contradictory to our expectations, as participants in STRUC received less autonomy support during the intervention period. Participants in AUT did not perceive more control or autonomy. This can be due to the fact that participants could not choose between multiple activities as in for example lifestyle interventions. However, it should be noted that the satisfaction of the need for autonomy (BPNES) did not differ between the two coaching groups.
In addition, the results showed that participants in STRUC reported a higher need satisfaction for the need for competence and relatedness in comparison with AUT (BPNES) ($P<.05$). Structure and assistance by a PA coach (3 times a week) in the old and old-old can increase feelings of competence. The higher feelings of competence are not surprising, as participants in STRUC had higher training frequencies and increased more in training volume (i.e., more challenging experiences) in comparison with AUT. Moreover, when residents exercise with significant others on a frequent basis (3 times weekly), feelings of relatedness (by others) can be more satisfied. I should mention here that perceived need support in both intervention groups was relatively high and that it is possible that feelings of one specific need can entail feelings of another need.

The SDT assumes that perceived need-satisfaction is associated with different types of motivation. Therefore, in addition to TASCQ and BPNES, the **quality of motivation** to participate in PA was measured using the Behavioral Regulation in Exercise Questionnaire-2 (BREQ) (Markland & Tobin, 2004). According to the SDT, motivation can be situated on a continuum, ranging from controlled (i.e., external regulation and introjected regulation) to autonomous motivation (i.e., identified regulation, integrated regulation and intrinsic motivation). Intrinsic motivation is located on the most autonomous (self-determined) end of the SDT-continuum as the behavior is highly internalized. The perceived satisfaction of the three needs is considered as fundamental in order to become more autonomously motivated in PA engagement (Ryan & Deci, 2000). The results of the BREQ-questionnaire revealed that participants in STRUC perceived higher levels of autonomous motivation at post-test in comparison with AUT (t=4.71; P=0.034). This finding is consistent with the abovementioned assumption of Ryan and Deci (2000) as participants in STRUC perceived higher levels of overall need support. Furthermore, the SDT hypothesizes that the more someone is autonomously motivated, the better the behavior will be sustained in the long-term (Ryan & Deci, 2000). However, in contrast with our expectations, no differences in adherence rate and frequency of training sessions per week were found between the two intervention groups, although participants in STRUC had higher training volumes during follow-up.

In conclusion, **autonomy-support has no additional effect on long-term adherence rate in the old and old-old.** It is possible that adults have other needs. With increasing age, variability in preferred amounts of control increases and there can be situations in which personal control is more likely to induce stress (Rodin, 1986). However, structured PA coaching can have an impact on training volume and on feelings of competence. The coach can stimulate participants to take up new PA challenges and set higher PA goals. Moreover, when residents exercise together, they can feel socially connected with the other participants (i.e., feelings of relatedness) (Hanson et al., 2014). In addition, as stated by Baert et al. (2011) an important barrier on the intrapersonal level for PA participation is the absence of an exercise companion (see Introduction 5.3.).
Finally, we should bear in mind that 'social attention' can play an important role as well. Individuals can modify their behavior in response to their awareness of being observed (research attention). This bias is better known as the 'Hawthorne effect' (Franke & Kaul, 1978). The improvement in feelings of need-support and/or autonomous motivation might be partially caused by the Hawthorne effect (i.e., social desirability answers, attention by the coach and significant others, social interaction with the coach and other residents).

2.4.3. *Effectiveness trial*



Note. Source: Courneya, 2010

The last type of exercise trials is the effectiveness trial. Effectiveness trials evaluate the effects of interventions under real-life conditions. They assume at least some level of non-adherence. At **the individual level**, ‘adherence rate’ (see 2.4.2.1.) and ‘reach’ can be put forward. ‘Reach’ gives more information about the proportion and characteristics of the target population that participated in the intervention (i.e., persons who receive or are affected by a policy or program). The participation rate can be calculated using the number of participants (numerator) and total population (denominator) (Glasgow, Vogt, & Boles, 1999). In ***Paper 4***, 95 residents (22.8% of 417 residents that were personally contacted) were included in the analyses. Mean age was 82 years old. As mentioned before, it is important to implement a recruitment strategy that also reaches those older adults that could benefit the most from an exercise program or intervention. Although this strategy requires a higher cost, less motivated and mobility restricted residents can be convinced to participate. In addition, information on non-participants can be of interest. Of the 417 residents that were contacted to participate in the cycle ergometer intervention, 25% of residents were not interested and 53% were excluded according to the exclusion criteria (i.e., physical/mental problems or cycle ergometer/bike in use). It would be interesting to examine why 25% of the residents was not interested to participate in the (free) intervention program. These factors can be taken into account in future studies when recruiting older adults living in assisted living facilities.

In contrast to efficacy trials that are less concerned about whether the intervention is feasible in practice, effectiveness trials typically adopt an intervention that is consistent with practice. As seen in *Figure 1*, an effectiveness trial determines whether an exercise intervention, achieved by a feasible behavioral support intervention is sufficient to improve health outcomes (Courneya, 2010). In our intervention study (cost-)effectiveness was taken into account. At **the organizational level,** 8 assisted living facilities, housing at least 35 residents, were randomly selected in Flanders/Belgium. An advantage of the intervention is the embedding in existing structures of assisted living facilities. Cycle ergometers were placed in common areas (e.g., cafeteria), and were accessible for all residents. Using existing structures to implement an intervention can substantially reduce the costs of a program and facilitates future implementation. Moreover, existing social networks can enhance the social support to be physically active. In addition, a cycle ergometer intervention was chosen as cycle ergometers can be used on a large scale because they are relatively cheap (i.e., several residents can use the device when placed in a common area), easy to use and because the majority of older adults have some experience with (ergometer) cycling. Even though a structured intervention program results in higher adherence rates and higher training frequency and volumes, minimal-contact coaching can still motivate older adults to start a cycle ergometer program.

Data gathered at the end of the intervention study in ***Paper 4*** revealed that all participating facilities were satisfied with the cycle ergometer intervention. Moreover, with regard to large-scale implementation, all intervention facilities had a cycle ergometer after follow-up measurements (‘adoption’). Future studies should examine the adoption, implementation and maintenance of ergometer cycling and minimal-contact coaching in assisted living facilities on the large scale.

PRACTICAL IMPLEMENTATION

Evaluating programs is important to avoid wasting resources and to improve public health to the desired level (e.g., PA recommendations) in the old and old-old. The efficacy and effectiveness of an intervention should be taken into account.

In conclusion, many studies pointed out the importance of PA (see 3.2. in the introduction) and the necessity to develop and implement PA programs in the old and old-old. As stated by Vellas, Cestac and Moley (2012), we should find a compromise between very strong interventions (e.g., high training intensities and frequencies) that will be adopted by only a small minority of older adults and too light interventions that are usually not strong enough to have a real impact. Moreover, because the aging of the population will further increase, long-term and sustained interventions need to be developed, taken into account cost and implementation possibilities (Vellas, Cestac, & Moley, 2012). The results of ***Paper 4*** showed small short-term improvements in functionality and lower body muscle strength, but only in those participants with an adherence rate of ≥80%. The results suggest that an adherence rate <80% (= ‘light intervention’) is not enough. On the other hand it proved difficult for the participants to exercise three times a week (see Table 3 ‘Cycle ergometer use’ in ***Paper 4***). The effects of a ‘stronger cycle ergometer intervention’ including higher training intensities should be studied, as there is more potential for improvements in this functionally limited age-group. However, training intensity may not be too high as higher intensity programs may be unacceptable to older adults with low exercise capacity or only acceptable when strictly supervised (Chin A Paw et al., 2006). Moreover, participants in ***Paper 4*** were already reluctant to increase training volume and are vulnerable for injuries and drop-out. In addition, most functionally-limited older adults, and especially the old and old-old do not feel the necessity of being physically active and do not always acknowledge the positive effects of regular PA.

Notwithstanding, an important finding of ***Paper 4*** was the feasibility of ergometer cycling in assisted living facilities. Training sessions were experienced as pleasant and almost all facilities decided to purchase a cycle ergometer. Although more structure and contact moments with a coach resulted in higher training volumes, the limited number of contact moments should be favored as it is more feasible in real life settings.

In the future, more attention should be given to the promotion of PA in assisted living facilities. Nowadays, only few facilities organize active recreational activities (Hanson et al., 2014; data

gathered during the intervention study, but not published or included in ***Paper 4***). PA should be recognized as a basic need and should be included as a ‘quality standard’ in assisted living facilities.
Support from the government is essential during this process as financial resources, staffing issues, physical space constraints and limited knowledge can hinder the promotion of PA. The government should support education on the health benefits of regular PA and the availability of PA programs in assisted living facilities. In addition, the general practitioner can play an important role (see 2.1.3.2. in the discussion) and should therefore point out the importance of a physically active lifestyle. PA is important, as it can have an important effect on social cohesion (next to the effects on biological outcomes). Also in ***Paper 4***, it was clear that residents had more social contact since the start of the exercise program and the placement of cycle ergometers in the common area (i.e., cafeteria).

3. TAKE HOME MESSAGES

Taken together, the present doctoral thesis offers important information regarding screening of older adults at risk for functional impairments; and regarding objective assessment and promotion of PA in older adults living in residential care facilities.

TAKE HOME MESSAGES

- The SWMini and hip-worn piezoelectric pedometer are insufficiently accurate for quantifying steps in the old and old-old. An ankle-worn piezoelectric pedometer can be useful in older adults walking faster than 2.35 km/h.

- The SWMini is of limited value for quantifying EE in nursing home residents. However, it can detect interruptions in sedentary time and is therefore a suitable device for researchers interested in patterns of PA and sedentary behavior.

- Grip strength and knee extension strength are both important predictors of functional performance in older adults. In assisted living facilities, knee extension strength is clearly more predictive than handgrip strength. Cut-off values for functionally relevant lower body muscle weakness, expressed in kg per kg BW, are 0.40 for men and 0.31 for women.

- Minimal contact with a PA coach is sufficient to promote cycle ergometer use in assisted living facilities, but training volumes are higher in both the short- and long-term when training is strictly supervised. Frequent use of a cycle ergometer shows better short-term results on functionality and muscle strength, even though improvements are small.

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APPENDICES

PROFESSIONAL CAREER SOFIE MARTIEN

2010 –2015	PhD student KU Leuven Faculty of Kinesiology & Rehabilitation Sciences Department of Kinesiology - Physical Activity, Sports & Health Research Group Policy Research Center on Sports, supported by the Flemish Government (2012 - 2015)
2009 - 2010	Research assistant KU Leuven Faculty of Kinesiology & Rehabilitation Sciences Department of Human Kinesiology
2009 - 2011	Teacher Qualification in Physical Education KU Leuven *Graduated magna cum laude*
2008 - 2009	Degree of Master of Physical Education and Kinesiology Major Subject Sports Management KU Leuven *Graduated summa cum laude*
2005 - 2008	Degree of Bachelor of Physical Education and Kinesiology KU Leuven *Graduated magna cum laude*

LIST OF PUBLICATIONS

Articles in internationally reviewed academic journals

Martien S, Delecluse C, Boen F, Seghers J, Pelssers J, Van Hoecke A, Van Roie E (2015). Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings? *Archives of Gerontology and Geriatrics,* 60 (2), 252-258. doi: 10.1016/j.archger.2014.11.010.

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Seghers J, **Martien S** (2009). Perceived school environment and physical activity behaviour in Flemish adolescents. *European Journal of Physical and Health Education,* 2 (1), 47-57.

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Seghers J, **Martien S** (2009). Schoolgerelateerde fysieke activiteit en het bewegingsgedrag tijdens de vrije tijd bij adolescenten in Vlaanderen. *Tijdschrift voor Lichamelijke Opvoeding,* 224, 8-11.

Reports

Delecluse C, Theeboom M, Westerbeek H, **Martien S**, Verheyden E (2012). Krachtlijnen voor een vernieuwd beweeg- en sportbeleid voor senioren in Vlaanderen [Strategies for a new sport and physical activity policy for Flemish older adults] - in opdracht van Vlaams Minister van Sport Philippe Muyters [conducted under the authority of the Flemish Minister of Sports Philippe Muyters] (Report). Brussels, BE: Flemish Government.

Meeting abstracts, presented at international scientific conferences and symposia

Martien S, Boen F, Seghers J, Delecluse C (2014). Are cycle ergometers effective to promote physical activity and physical function among older adults? Short-term effects of a 10-week structured versus need-supportive physical activity program in assisted living facilities. *10th Annual Meeting and 5th Conference of HEPA Europe*. Zürich, 27-29 August 2014.

Martien S, Seghers J, Boen F, Delecluse C (2013). Validation of two motion sensors to assess daily physical activity in institutionalized elderly. *IAGG Congress of Gerontology and Geriatrics*. Seoul, 23-27 June 2013.

Van Hoecke A, Delecluse C, Opdenacker J, Lipkens L, **Martien S**, Boen F (2013). Long-term effectiveness and mediators of need-supportive physical activity coaching among Flemish sedentary employees. *ISBNPA Conference*. Ghent, 22-25 May 2013.

Van Hoecke A, Delecluse C, Opdenacker J, Lipkens L, **Martien S**, Boen F (2011). Long-term effectiveness and mediators of need-supportive coaching on physical activity and well-being among sedentary employees. *HEPA Conference Europe*. Amsterdam, 11-13 October 2011.

Van Hoecke A, Delecluse C, Opdenacker J, Lipkens L, **Martien S**, Boen F (2011). Long-term effectiveness and mediators of a need-supportive physical activity coaching among Flemish sedentary employees. *European Congress of Sport Psychology*. Madeira, 12-17 July 2011.

Meeting abstracts, presented at other scientific conferences and symposia

Van Hoecke A, Delecluse C, Opdenacker J, Lipkens L, **Martien S**, Boen F (2012). Long-term effectiveness and mediators of need-supportive coaching on physical activity and well-being among sedentary employees. *Belgian Nutrition Society*. Brussels, April 20th 2012.

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APPOSITIONS – BIJSTELLINGEN

Bijstelling 1

In de context van veroudering vormen eenzaamheid en sociale isolatie belangrijke uitdagingen. Fysieke activiteit kan hierbij een belangrijke rol spelen en verdient daarom voldoende aandacht.

Bijstelling 2

Onderzoek heeft aangetoond dat bewoners van de vijf blauwe zones - beter gekend als ‘blue zones’ - langer, gezonder en gelukkiger leven. Onderzoek dient na te gaan of een stijging van het aantal ‘blue zones’ kan resulteren in een daling van de kosten van gezondheidszorg.

Bijstelling 3

Als gevolg van de toenemende vergrijzing worden steeds meer ouderen geconfronteerd met dementie. Fysieke activiteit kan het dementieproces positief beïnvloeden. Gepaste interventiestrategieën ter promotie van fysieke activiteit dienen ook voor deze doelgroep ontwikkeld te worden.